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INVESTIGATION OF USE OF GEL MATERIAL FOR MINE SEALING

Nevill K. Chung

Dravo Corporation

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Investigation of Use of Gel Material for Mine Sealing

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INVESTIGATION OF USE OF GEL MATERIAL FOR MINE SEALING

By

Neville K. Chung

Project 14010 EKW

Project Officer

Ronald D. Hill
Mine Drainage Pollution Control Activities
Environmental Protection Agency
National Environmental Research Center
Cincinnati, Ohio 45268

Prepared for

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Laboratory testing of commercially available chemical grouts was conducted to evaluate their potential use, in conjunction with a cheap filler, for remote sealing of mine voids. By close control of the setting time and proper distribution of the grout slurry it was believed that a mine seal could be placed through a borehole from the surface without the benefit of retaining bulkheads.

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SECTION I

CONCLUSIONS

1. A slurry consisting of an acrylamide grout with flyash or neutralized mine refuse as a filler can produce a stiff gel which may be useful in remote sealing of mine voids. The setting time is controllable, and the gel material is strong, resilient and resistant to attack by mine acid.

2. The cost of the materials and placement are at present higher than that for a concrete seal. Reductions are possible through use of a modified mix, possibly with cement as an admixture, and refinement of injection procedures.

3. Dilution and erosion of the gel material prevents successful formation of a gel seal in high flow mines. Application of the material and technique to dry or low flow situations has not been tested.

4. A concrete seal can be placed between ungrouted stone bulkheads but settling of the concrete may occur due to movement of the unconsolidated aggregate, resulting in increased grout requirement in the subsequent pressure grouting operation.

SECTION II

RECOMMENDATIONS

1. It is recommended that a groundwater monitoring program be included in plans for completion of mine drainage abatement work at the Salem No. 2 Mine at Keystone State Park, since information is lacking at the present time regarding the effect of mine sealing on groundwater conditions, and monitor wells have already been drilled at the Keystone site.

2. The location of the mine portal area on State property which is not developed presently for recreational use, and the existence of a reinforced concrete safety bulkhead with view ports and sample valve, make the site ideal for further test work. It is recommended that this asset be explored prior to making a final decision on sealing. If no testing is foreseen, closing of the drain valve and sample valve in the bulkhead will make it a concrete seal.

3. It is recommended that grout stabilization of the stone bulkheads be retained as normal procedure in construction of double bulkhead seals.

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SECTION III

INTRODUCTION

Acid mine drainage is formed by the oxidation of iron disulfides, usually pyrites, found in association with coal, when the pyrites are exposed to air and water. The result is a dilute solution of sulfuric acid and iron sulfate. Though there are available treatment techniques, such as neutralization with lime to adjust pH and precipitate iron, it is generally agreed that measures aimed at preventing the formation of acid drainage hold the most promise for curbing this source of pollution, particularly from inactive mines.

There are presently over 3000 miles of streams in Pennsylvania affected by mine drainage, most of it originating from abandoned deep mines. Estimates for abatement have been set at two billion dollars, and the major portion of this cost is for source control. New techniques are constantly being sought, largely through research and development programs sponsored by the U. S. Environmental Protection Agency and various State agencies.

Previous Investigations

Techniques which have been investigated for the prevention of mine acid formation are based on excluding oxygen from the pyritic surfaces. This is usually accomplished by sealing the mine openings to prevent entry of air and to cause the mine cavity to fill with water.

Seal construction methods tested have included:

a) placement of an aggregate mass followed by injection of grout into the aggregate.

b) placement of a permeable limestone plug for in situ neutralization and sealing by precipitates.

c) injection of quicksetting cement grout into expendable cloth retainers.

d) formation of forward and rear retaining bulkheads with a quick-setting slurry followed by injection of a cement intermediate plug.

e) placement of forward and rear retaining bulkheads of aggregate through vertical boreholes, followed by

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stabilization of the bulkheads by injection of grout and injection of a concrete plug between the bulkheads.

The last method, using two bulkheads of stone with a concrete plug between them, was recently employed in sealing over 100 mine openings in Butler County, Pennsylvania.

Purpose and Scope of Present Study

The work reported herein was undertaken to develop a new mine sealing technique using a chemical grout with a filler material as the sealant. A chemical grout is a mixture of chemicals which will produce a stiff gel from a dilute aqueous solution when properly catalyzed. The setting time is predictable and controllable, and the gel material is essentially impermeable. It was theorized that a chemical grout with a cheap filler such as flyash could produce a strong, chemically resistant, impermeable material suitable for a mine seal, and that by proper distribution of the grout slurry and control of the gel time the seal could be built up without the benefit of retaining bulkheads.

Three major phases of activity were proposed:

1) Laboratory testing of commercially available grouts and filler materials to evaluate and select one or more formulations suitable for the proposed remote mine seal construction.

2) Demonstration of a technique for application of the gel material by sealing three entries of an abandoned deep mine located in Derry Township, Westmoreland County, Pennsylvania.

3) Post-construction surveillance to study the effectiveness of the seals, and to determine changes in groundwater quantity or quality resulting from placement of the seals.

As the work progressed, information developed in each phase suggested or dictated changes to the original scope of work in succeeding phases. Two major changes were made:

1) Double bulkhead type concrete seals, with ungrouted stone bulkheads, were placed in two of the three mine entries, and only one chemical grout seal attempted.

2) The post-construction groundwater monitoring program was postponed.

Although the surveillance program was not performed, a set of groundwater monitor wells were completed in order that background information regarding groundwater level and quality could be developed prior to placement of any mine seal. This information, plus data on the flow and quality of acid drainage from the mine, and stratigraphic information developed from drilling of the monitor wells, are included in this report to provide a reference point for future work if performed at this site. The need for information regarding the effect of mine sealing on groundwater still exists, and it is assumed that this aspect will be investigated when the sealing of the mine is completed by injection of grout curtains.

SECTION IV

DEVELOPMENT OF SEAL MATERIAL

Test Objectives

As proposed, the experimental mine seal was to be built by injection of a gel material with controllable setting time into the mine cavity through a vertical borehole from the surface. The material would be self-supporting, eliminating the need for retaining bulkheads. Following placement of the seal, flyash would be pumped into the mine side of the seal. The purpose of this backstop was twofold. It was felt that if any leakage occurred flyash would be carried in suspension into the seal and plug the leak. Secondly any leakage that escaped the seal would be neutralized by the flyash. A sketch of the proposed seal is shown on Figure 1. The safety bulkhead shown is for protection during development and testing of the seal.

Test work to develop a material suitable for the proposed mine seal included evaluation of five different chemical grouts with various combinations of flyash, mine refuse, sand and gravel as fillers. Characteristics of prime importance were a short, controllable setting time, resistance to chemical attack by mine acid, and sufficient strength to withstand expected forces.

To avoid formation of a point seal at the injection hole which would prevent completion of the seal across the entire width of the mine roof, it was felt that it would be necessary to direct the grout slurry stream outward away from the injection hole, and slightly upwards, in order to build the seal up from the outer extremities in a concave shape, as shown on Figure 2. A short gel time of less than one minute would be required while building up the seal in order to give an economical angle of repose and prevent excessive running of the material along the mine floor. On the other hand during the final stages a longer gel time would be required to ensure dispersion and penetration of the grout into the remaining crevices. For maximum flexibility it was decided that the material should have a highly controllable gel time from greater than five minutes to a few seconds.

The mine floor at the test site slopes upward from an elevation of 1016 feet at the entry to a maximum elevation of approximately 1100 feet. The maximum hydraulic head that could develop on a seal therefore is approximately 84 feet, equivalent to 36 psi. The maximum pressure which

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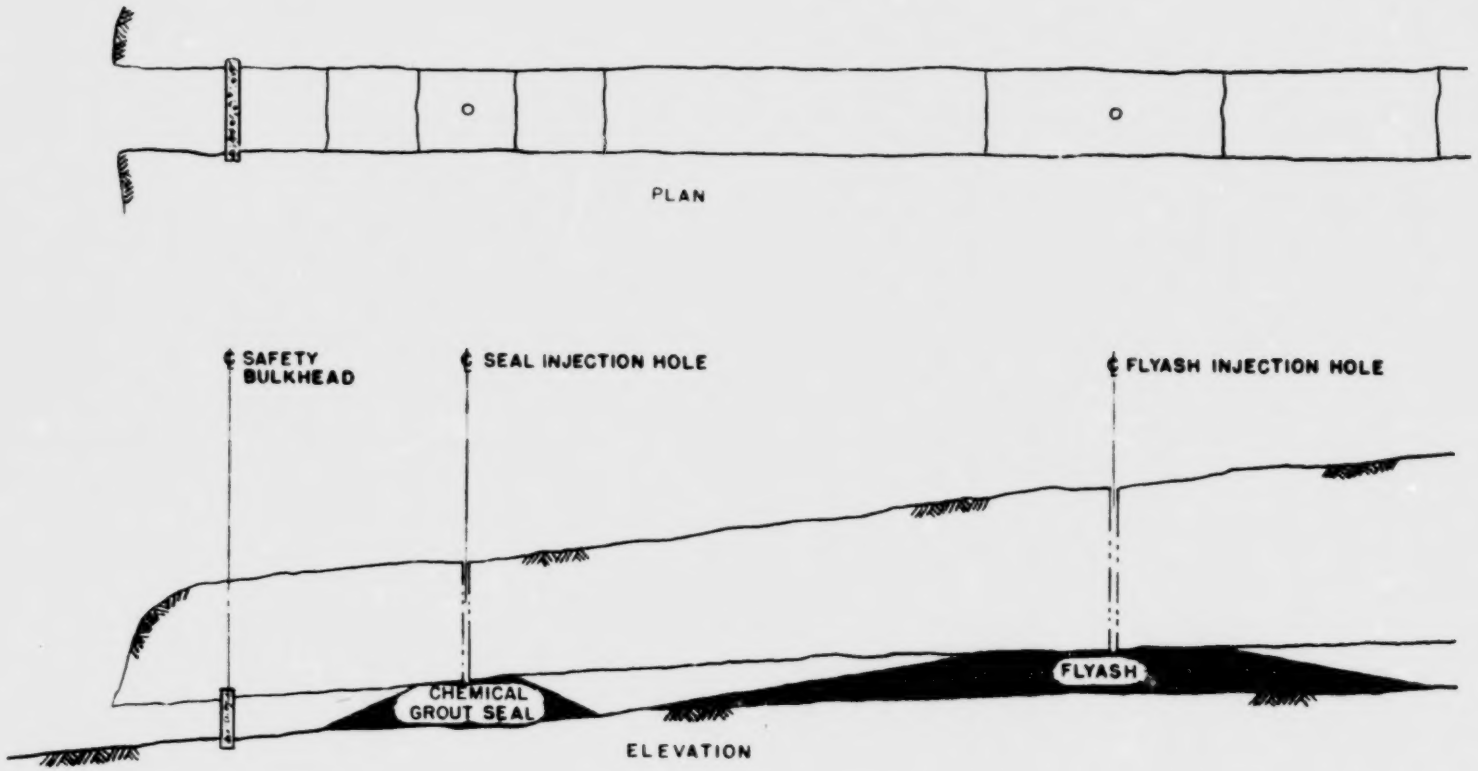


FIGURE 1. ARRANGEMENT OF PROPOSED MINE SEAL

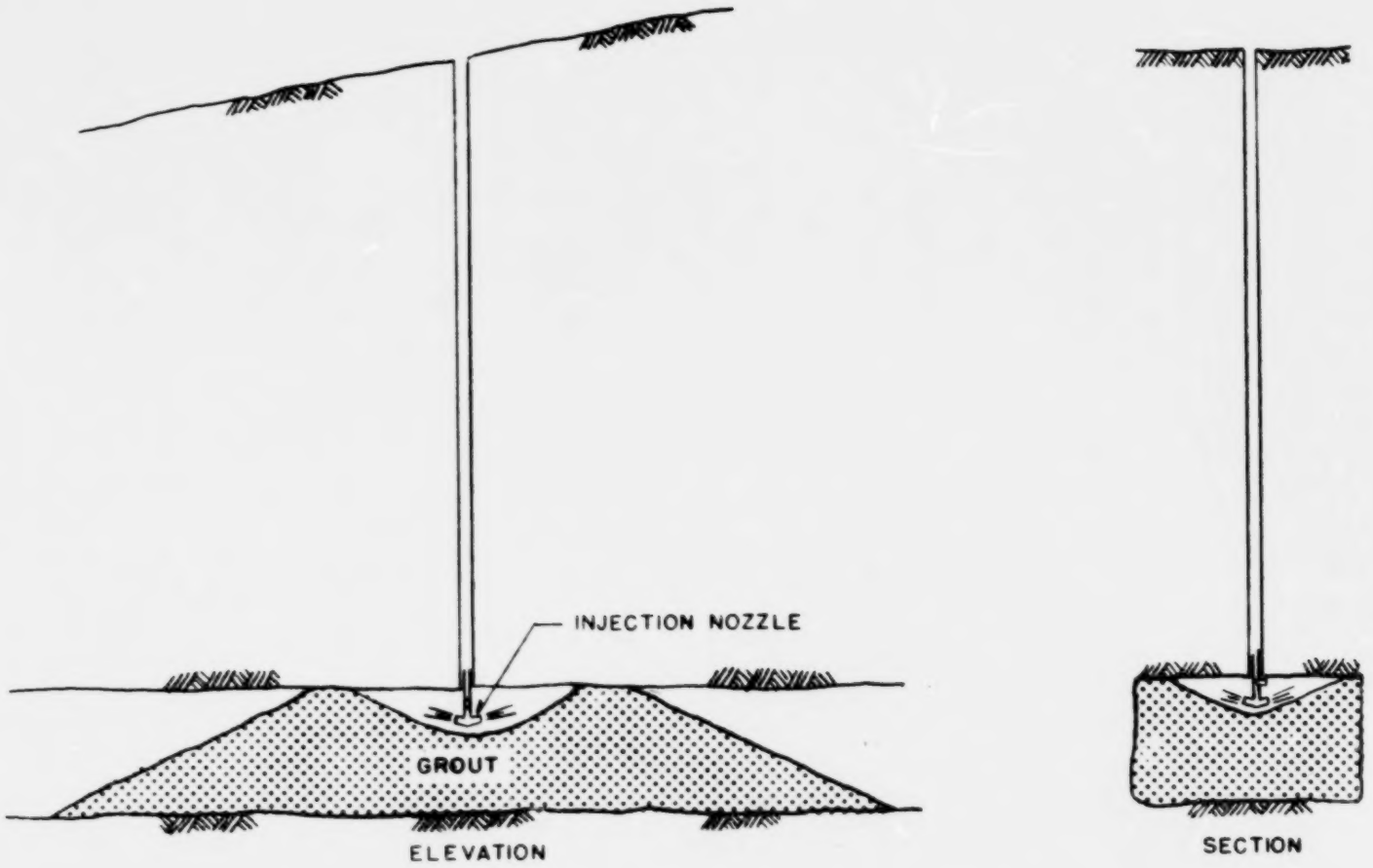


FIGURE 2. INJECTION PROCEDURE FOR GROUT SEAL

could be exerted by the overburden of about 30 feet was estimated at 35 psi, essentially equivalent to the maximum hydraulic head. Using a design safety factor of 3, which includes allowances for differences in filler materials and between laboratory techniques and field procedures, a compressive strength of 110 psi was selected as the desired strength of a seal material.

Chemical Grouts Tested

Five commercially available chemical grouts were tested:

Trade Name	Type
Terranier-C	Phenolic polymer
AM-9	Vinyl polymer
Cyanaloc-62	Methylol bridge polymer
Terra Firma	Chrome lignin
Geoseal	Phenolic polymer

Terranier-C is a three-component system consisting of a principal reactant, a catalyst and a secondary reactant or crosslinking agent. The principal reactant is a phenolic powder which is dissolved in water to make one solution. A second solution is prepared containing the catalyst, sodium dichromate, and a formaldehyde cross-linking agent. A polymerization-crosslinking reaction occurs when the two solutions are mixed.

AM-9 Chemical Grout is a four-component system consisting of a reactant, catalyst, inhibitor and initiator. The reactant is a mixture of two organic monomers, acrylamide and N,N'-methylenebisacrylamide. It is a granular material which is mixed with water to make a solution of desired strength. The catalyst is B-dimethylaminopropionitrile (DMAPN) an alkaline liquid. The inhibitor potassium ferricyanide, is added in very small quantities to control the reaction.

The reaction is triggered by the initiator, ammonium persulfate, which is a very strong oxidizing agent. Two solutions are prepared, one containing AM-9, DMAPN and potassium ferricyanide, and the other ammonium persulfate. Gelation occurs by a polymerization-crosslinking reaction when the two solutions are mixed.

Cyanaloc-62 consists of two components, a reactant and a catalyst. The reactant is a viscous liquid monomer which is diluted to desired strength with water. Polymerization occurs when a solution of sodium bisulfate, the catalyst, is mixed with the reactant.

Terra Firma consists of a lignosulfonate reactant which is catalyzed by sodium dichromate to form a chrome lignin gel. Both materials dissolve readily in water to make solutions of desired consistency for application.

Geoseal is a two-component system consisting of a phenolic reactant and sodium hydroxide catalyst. The reactant is a powder which is not dissolved in water, but added directly to a solution of the catalyst. Polymerization occurs when the two are mixed in certain proportions which give a pH of between 9.5 and 10.2.

Fillers Tested

Flyash was the first material considered for testing as a filler. It is cheap and readily available, and was also proposed as a backstop behind the seal because of its particle size and alkalinity. For the laboratory testing 800 lb of flyash was obtained from Duquesne Light Company's Elrama, Pa. station. This sample of ash had a particle density of 2.11 gm/cc and a bulk density of 1.05 gm/cc, indicating approximately 50% voids.

Mine refuse from the mine site was investigated as a possible filler material since if successful this would also solve, at least partially, the problem of disposal of this unsightly acid producing waste material. The loosely compacted, claylike material was found to have a particle density of 2.35 gm/cc and a bulk density of 1.53 gm/cc, indicating 34% voids. The material is acidic with a pH of approximately 3.0.

Shot gravel and Ohio River highway grade sand were tested briefly and found to offer no advantages over flyash or mine refuse as fillers for the proposed seal material.

Testing Procedures

Preliminary tests were run with each material to determine its particular characteristics and suitability as a potential mine sealant. Mix proportions, strength, gel time control, and compatibility with the fillers were evaluated. Once these tests were completed, practicable grout formulations were selected for further testing of physical properties and stability.

Test cubes were prepared by mixing selected proportions of grout, water, filler and whenever necessary inhibitor or crosslinking agent, for thirty minutes to insure homogeneity, adding the catalyst or activator, and pouring the slurry into ASTM standard 2-inch cube molds shown on Figure 3. After solidification the cubes were placed in a storage vault with humidity controlled at 100% to prevent dehydration. Two or three cubes were tested for compressive strength daily for one week. (Figure 4.) After the first week cubes were tested once per week for ten weeks. Figure 5 shows the controlled-humidity storage vault.

Resistance to chemical attack from acid mine drainage was tested by submerging cubes in an acid solution prepared in the laboratory to simulate the most severe condition anticipated. This solution contained 200 ppm iron, 400 ppm sulfate, and had a pH of 2.0. Size, compressive strength, and weight of test cubes were checked weekly for ten weeks. The test solution was examined for discoloration and sediment, and changed weekly or whenever the pH value reached 3.5.

Evaluation of Grout Slurries

The preliminary tests which were conducted with each material eliminated some of the materials and certain combinations of materials from further, long-term testing. Shot gravel and highway grade sand were tested as fillers for added mass in combination with flyash and mine refuse. They were found to yield lower compressive strength than either flyash or mine refuse alone, and were therefore eliminated from further consideration as fillers.

Tests with Terra Firma indicated that the gel time could be effectively controlled only by varying the water content, which affected the strength of the resultant gel. Catalyst concentration was dependent on monomer concentration, which resulted in shorter gel times with increasing concentrations of the chemical grout. This system was also found to be incompatible with flyash due to the alkalinity which results in precipitation of trivalent chromium from the dichromate catalyst.

Geoseal is catalyzed by sodium hydroxide at a pH between 9.5 and 10.2. The caustic not only initiates the reaction but is also necessary to dissolve the reactant to a true solution. Polymerization therefore begins as soon as the reactant is dissolved in the catalyst solution. This necessitates a batch, or one-shot, system of application

FIGURE 3. PREPARATION OF TEST CUBES

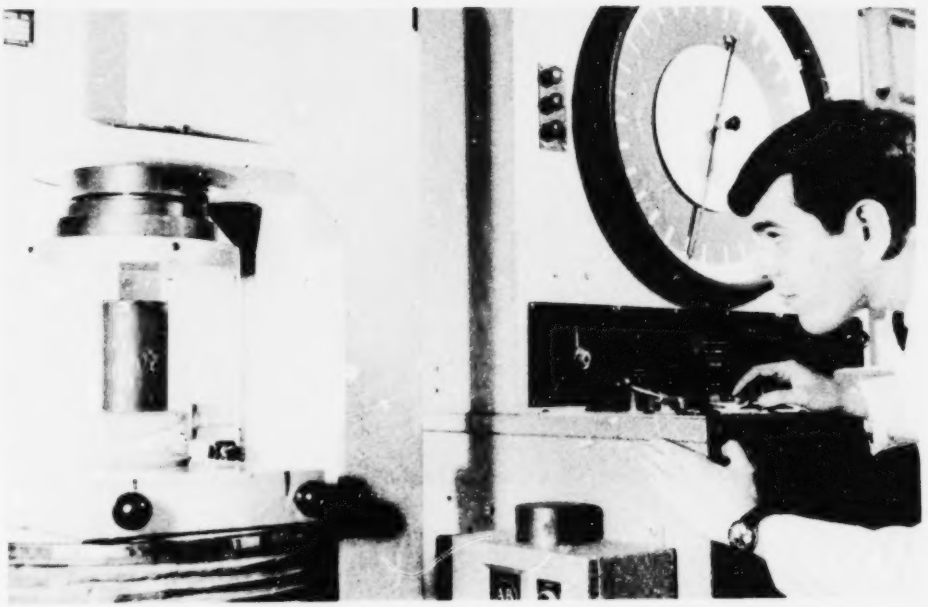


FIGURE 4. UNCONFINED COMPRESSIVE STRENGTH TEST

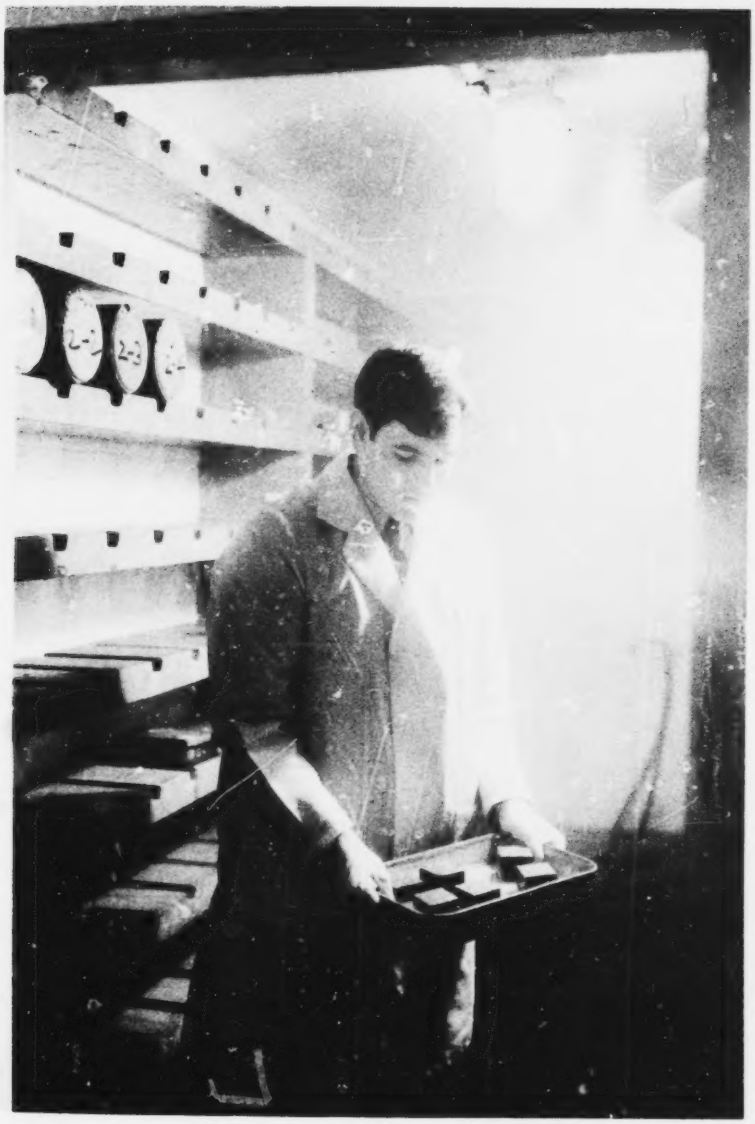


FIGURE 5. TEST CUBE STORAGE IN CONTROLLED-HUMIDITY VAULT

which severely limits control of gel time and precludes use of a very short gel time. A two-shot system was devised by preparing the grout solution with less sodium hydroxide than is necessary for gelation, and feeding the remainder of the required caustic in a separate stream. In theory this seemed feasible, but it could not be made to work. The material increased in viscosity but would not gel. An increased amount of caustic caused a gel which was attacked by moisture indicating only a partial reaction.

The addition of either flyash or mine refuse to a solution of Terranier-C was found to start gelation immediately, apparently due to a catalytic effect of polyvalent cations in the fillers. It was discovered that a more stable mixture, usable for 30 to 40 minutes, could be prepared by adding dry Terranier-C to a flyash slurry or neutralized mine refuse slurry. Test cubes made in this manner were found to be hard and brittle with compressive strength of 70 to 115 psi. When the cubes were immersed in a synthetic mine acid solution, the solution turned a dark reddish-brown color characteristic of the polymer within one day.

Leaching of color continued for about seven weeks, during which time the cubes shrank approximately 5% in volume, but no corresponding loss of strength was detected. This loss of color and shrinkage may indicate a condition which could eventually lead to failure; however the immediate problem with use of Terranier-C slurry as a mine sealant was the initiation of setting by the fillers.

Cyanaloc-62 is acid catalyzed and therefore will not form a gel with alkaline flyash. With mine refuse as a filler gelling is initiated but proceeds very slowly, over a period of hours. Test cubes made with a grout mix consisting of 25 pounds mine refuse to 1 gallon of one-to-one by volume Cyanaloc-62 solution had compressive strength of 560 psi. However, after five weeks immersion in an acid solution the cubes began to show signs of deterioration. The surface developed a slimy appearance, and an 8% weight loss was measured. A sudden, severe loss of strength occurred during the eighth week. At the end of the ten week test period the strength loss was 42% due to attack by the acid. Test cubes stored at 100% humidity showed no similar loss of strength.

Testing of AM-9 chemical grout was narrowed down to 10% and 15% solutions after preliminary tests. The exothermic

polymerization reaction released enough heat to cause cracking of cubes made with a 30% solution, and a 5% solution produced a very weak gel. The 20% solution was eliminated from further testing after three weeks because indications were that satisfactory strength would be obtained with a 15% solution.

Both flyash, and mine refuse neutralized with lime or flyash, were found to be compatible with AM-9. Test cubes were made using 10% and 15% AM-9 solutions with the following amounts of filler per gallon:

a) 15 lb flyash

b) 20 lb mine refuse, 22 gm CaO

c) 7 lb flyash, 14 lb mine refuse

All the components of the AM-9 system were easily handled and readily dissolved to true solutions with viscosities similar to water. Mine refuse alone was found to be unsuitable as a filler because of its acidity, but neutralization to a pH greater than 7 with either lime or flyash made it an acceptable filler.

Gel time of AM-9 grout mixes was found to be highly controllable by varying the amounts of catalyst DMAPN, ammonium persulfate and potassium ferricyanide which together comprise the catalyst system.

Grout mixes made with AM-9 were found to produce a material which had a certain degree of elasticity. Figure 6 is a plot of observed deformations of cubes made with 10%, 15% and 20% AM-9 solutions and flyash versus applied compressive stress. Elasticity of a test cylinder is illustrated on Figure 7 which shows extreme deformation at failure. It is believed that this property would be advantageous in formation of a tight seal, after leakage is stopped by pressure grouting or by flyash carried in suspension from the backstop.

Compressive strength and size of test cubes immersed in an acid solution simulating mine drainage were measured weekly over an eleven week period. Figures 8 and 9 show the compressive strengths and volume changes observed for test cubes made using AM-9 with flyash alone and a combination of mine refuse and flyash as fillers. From the graphs it would appear that the chemical stability of the cubes made with a combination of flyash and mine refuse as filler

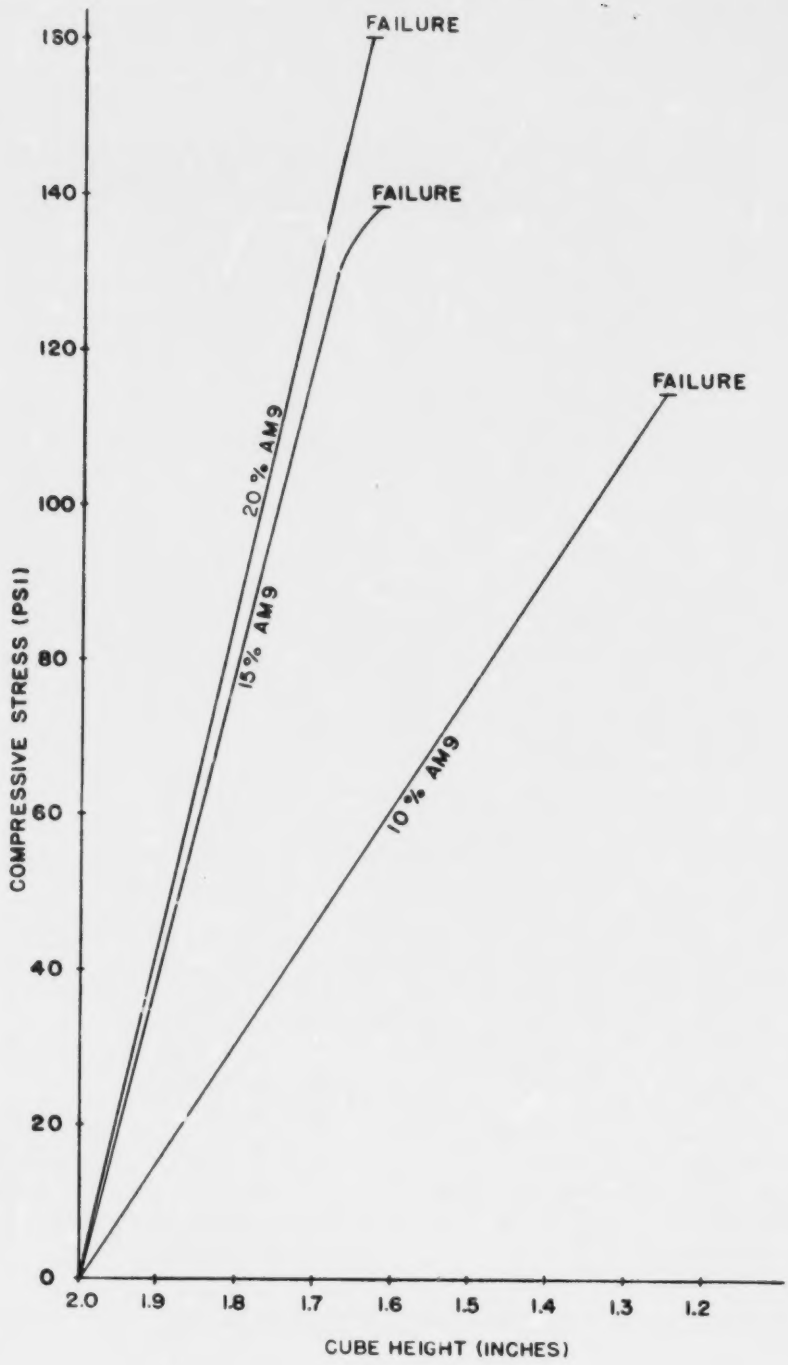
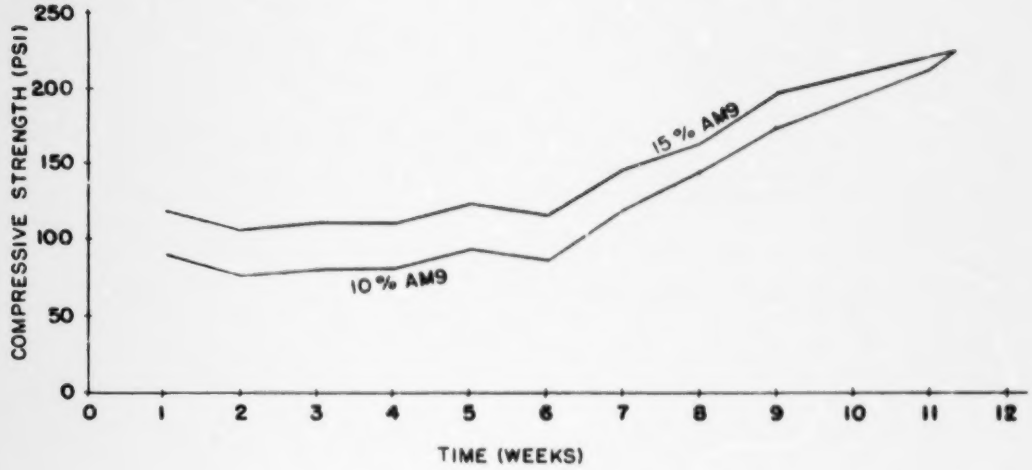


FIGURE 6. ELASTICITY OF FLYASH-AM9 GEL

FIGURE 7. DEFORMATION AND FAILURE OF TEST CYLINDER



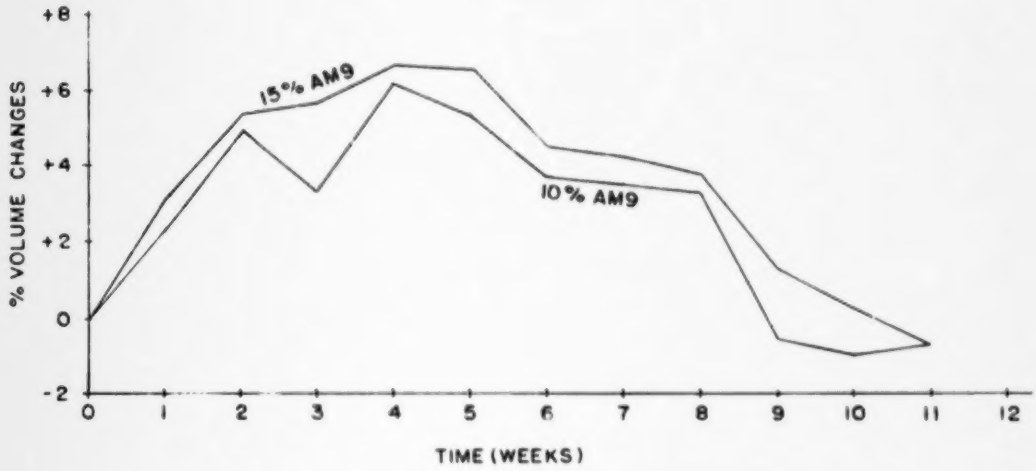
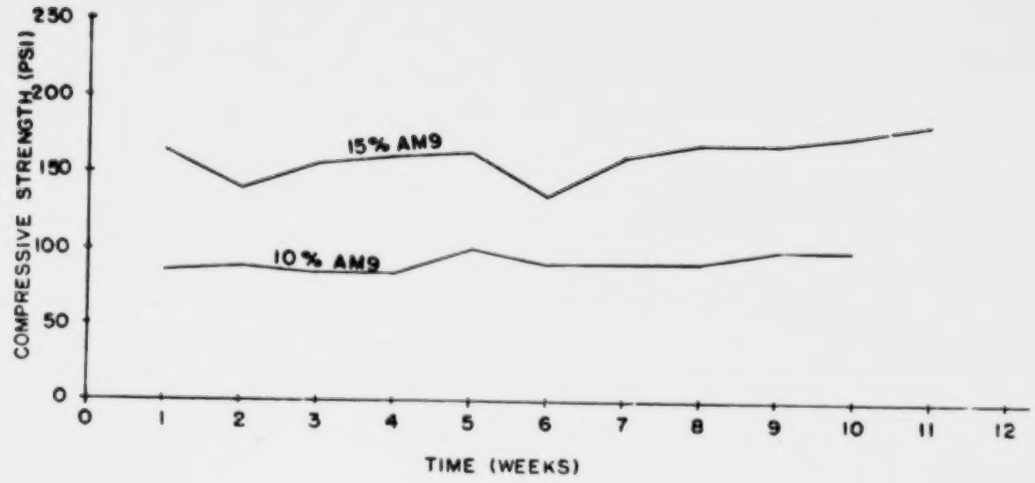


FIGURE 8. COMPRESSIVE STRENGTH & VOLUME CHANGES OF FLYASH-AM9 GEL IMMERSED IN ACID SOLUTION



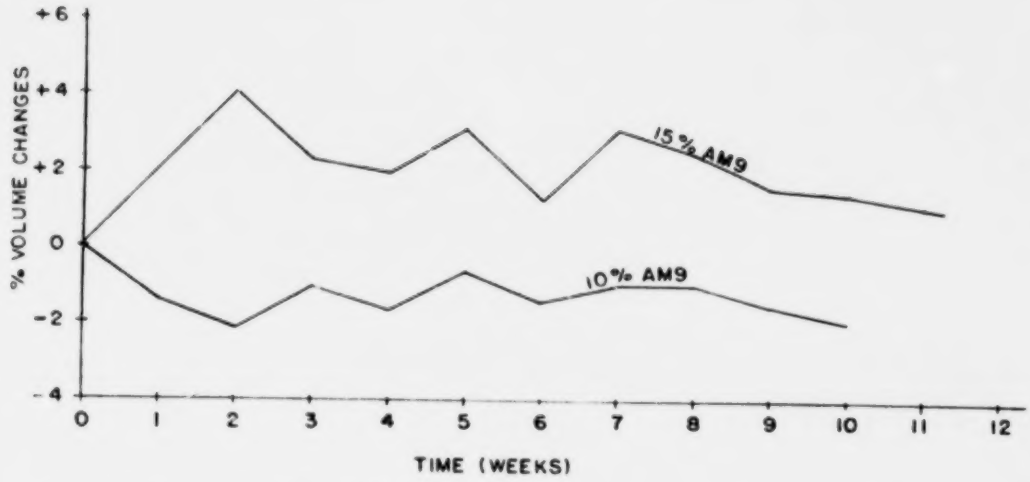


FIGURE 9. COMPRESSIVE STRENGTH & VOLUME CHANGES FOR MINE REFUSE-FLYASH-AM9 GEL IMMERSED IN ACID SOLUTION

is better than that of the cubes made with flyash alone as the filler. However it is believed that the observed variations in the strength and size of the cubes made with flyash alone were due to neutralization of flyash particles by acid at the surface of the cubes rather than to reaction with the chemical grout material itself, and a stable condition would be reached. When gels were formed at a lower pH by neutralizing the flyash with mine refuse (or vice versa) the observed strength and size were uniform.

It should be noted that strength determinations are made by destructive testing and that therefore each determination is made on a different cube prepared from the same grout mix. As a result some variation of observed strength can be expected from cube to cube, regardless of the curing time or exposure conditions.

Selected Grout Mix

Of the five chemical grouts tested only AM-9 was found to meet all the essential requirements of adequate strength, good gel time control and resistance to mine acid. The compressive strength tests indicated that a 15% AM-9 solution would be required, whether flyash or mine refuse was used as the filler. On the basis of a seal 12 feet wide by 28 feet long, the cost of grouting chemicals alone was estimated at $9,000 per seal. This was considerably higher than original estimates, which had been based on use of a cheaper grout material, and it appeared that even if the material could be cheaply applied the overall cost would exceed that of alternate sealing techniques.

It was agreed in a joint meeting with the project sponsors to proceed with only one experimental grout seal, and seal the other two mine entries with double bulkhead type concrete seals. Though the cost of the gel seal was expected to be uneconomical, it was felt that testing of the injection technique was still desirable since if successful, further research could be directed to reducing the cost of both the materials and the procedure.

A grout slurry of 15 lb flyash to one gallon of 15% AM-9 solution was selected for the test. Flyash offered certain inherent advantages over mine refuse as a filler for the proposed seal. Screening and neutralization were not required, as with mine refuse. Also, since one aspect of the proposed sealing operation consisted of pumping flyash into the mine side of the grout seal, the use of flyash as the filler would further simplify materials

handling. The main reason for considering mine refuse lay in the disposal aspect. However, in view of the variable nature and quantity of this material from mine to mine, any success with use of the material at this mine would not necessarily be repeatable at another site.

SECTION V

LOCATION AND DESCRIPTION

OF TEST SITE

Mine Location and Description

The site selected for demonstration of the experimental sealing material and technique is an abandoned deep mine located in Derry Township, Westmoreland County, Pennsylvania. Most of the mine, including the portal area, is located within the Commonwealth of Pennsylvania's Keystone State Park, approximately 35 miles east of Pittsburgh. The location is shown on Figure 10.

The mine, which was known as the Salem No. 2 Mine, covers approximately 300 acres, sloping upward at an approximate grade of 3% from an elevation of 1016 feet at the entrance to approximately 1100 feet at the highest point. There were three openings located a short distance below the spillway of Keystone Lake. The west opening was the main portal, while the middle opening served as a fanway. The third opening to the east was made by blowing a hole through the mine roof by an explosive charge set within the mine. The mine portal area is shown on Figure 11.

The main entry extends approximately half a mile in a southerly direction beneath a wooded hill. Side entries run east and southwest from the main entry. Beneath the crest of the hill the mine lies some 200 feet below the ground surface. Other than the portal area the thinnest cover occurs in the southernmost extremities where the mine is 40 to 60 feet below the ground surface.

A 12" air vent, located approximately 200 feet up from the main entrance as shown on Figure 11 was the only other opening found into the mine. No instance of subsidence was known to a former miner who worked in the mine for 20 years, and no evidence of holes or slumps were found during field inspections of the mined area.

All three entries were blocked with rubble, and acid drainage appeared to be coming only from the middle entry in front of which the water was pooled. The overflow drained into the small creek below the Lake. This creek enters the Loyalhanna Creek, a tributary of the Allegheny River, approximately 1-1/2 miles downstream.

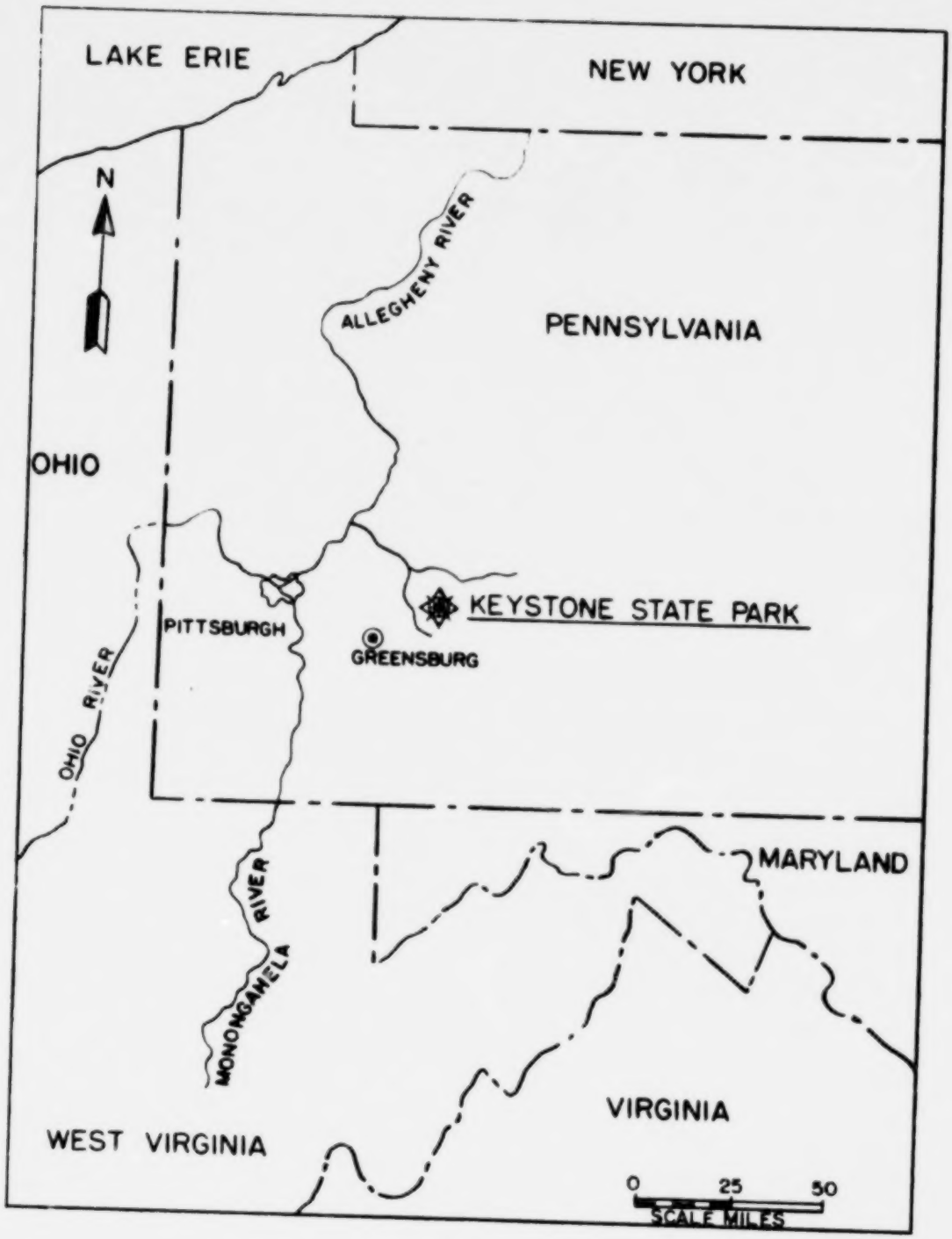


FIGURE 10. GENERAL LOCATION MAP

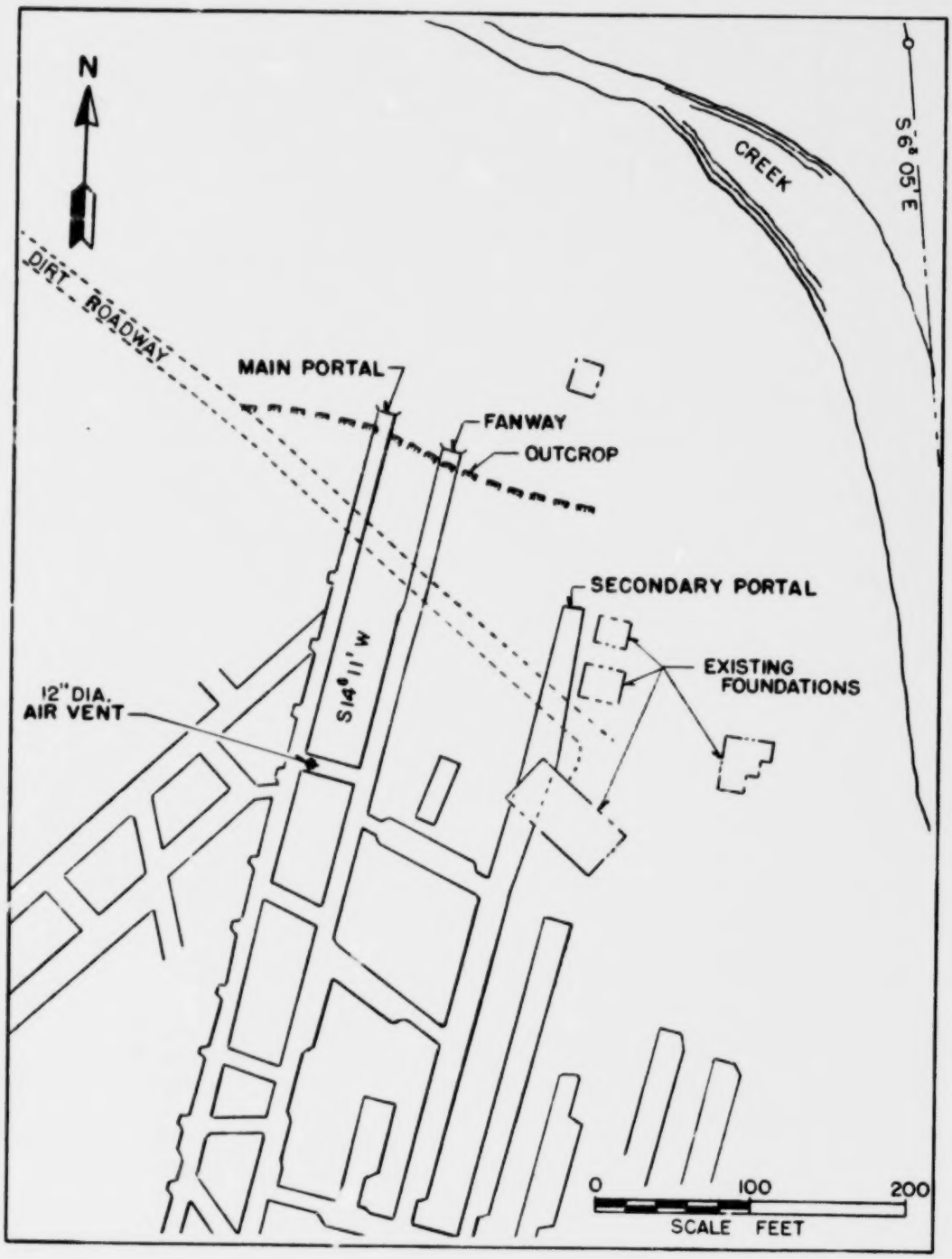


FIGURE 11. MINE PORTAL AREA

Acid Drainage Characteristics

The acid drainage from the mine was measured and sampled over a two-year period prior to the start of remedial activity, from October 1967 to August 1969. The flow generally ranged from 20,000 gallons per day (13.9 gpm) to 160,000 gallons per day (111 gpm), with the lowest flows occurring in late summer and fall, and the highest flows occurring usually during the first three months of the year. Figure 12 shows the flow variation over the two-year sampling period. Flow rates plotted are single measurements or averages of two to four measurements taken during a given month. Occasional peak flows up to 850,000 gallons per day (590 gpm) were reported; however ninety percent of the time the flow was less than 160,000 gallons per day, and half the time less than 60,000 gallons per day, as shown by the statistical analysis of all recorded flow measurements, Figure 13.

Concentrations of iron, acidity and sulfate in the mine drainage over the sampling period are shown on Figure 14, and the corresponding loadings in pounds per day are shown on Figure 15. Again the values plotted are either single determinations or averages of two to four samples taken during a given month. The total pollution load due to the mine drainage is related primarily to the flow quantity and only secondarily to contaminant concentrations. Peak loads generally coincided with high flow periods.

Inasmuch as the mine drainage flow, and consequently the pollution load, may be a function of the wetness or dryness of any given period, an evaluation of abatement measures should take into consideration the amount of precipitation in the area over the study period. The terrain above the mine is conducive to fairly rapid surface runoff on all sides of the rounded hilltop. However infiltration that does occur will find its way into the mine cavity which, by virtue of its areal extent and the relatively unimpeded routes it provides, should be the principal flow control for subsurface water. Precipitation data for the Keystone State Park area for the years 1967, 1968 and 1969 is given on Table 1.

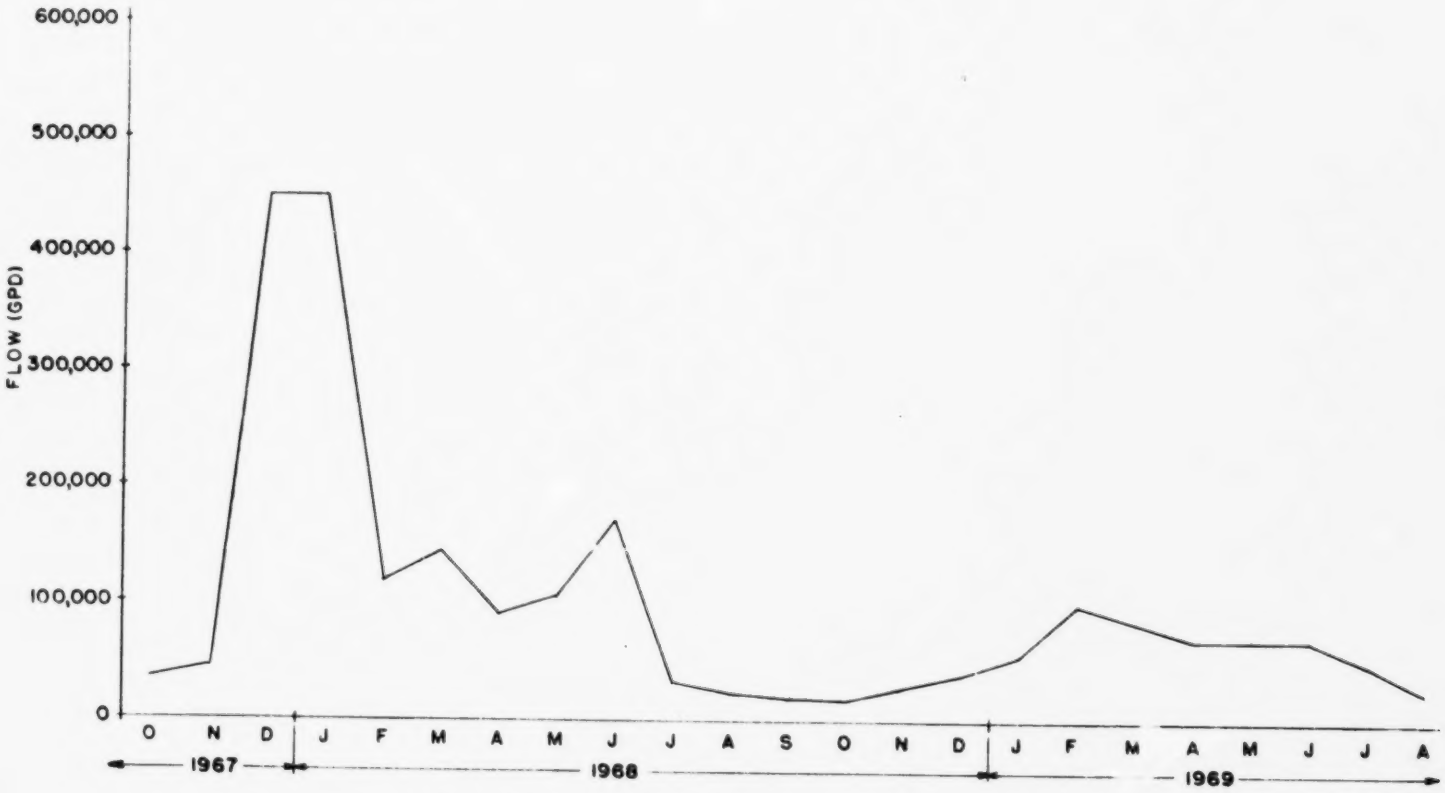


FIGURE 12. ACID DRAINAGE FLOW VARIATION

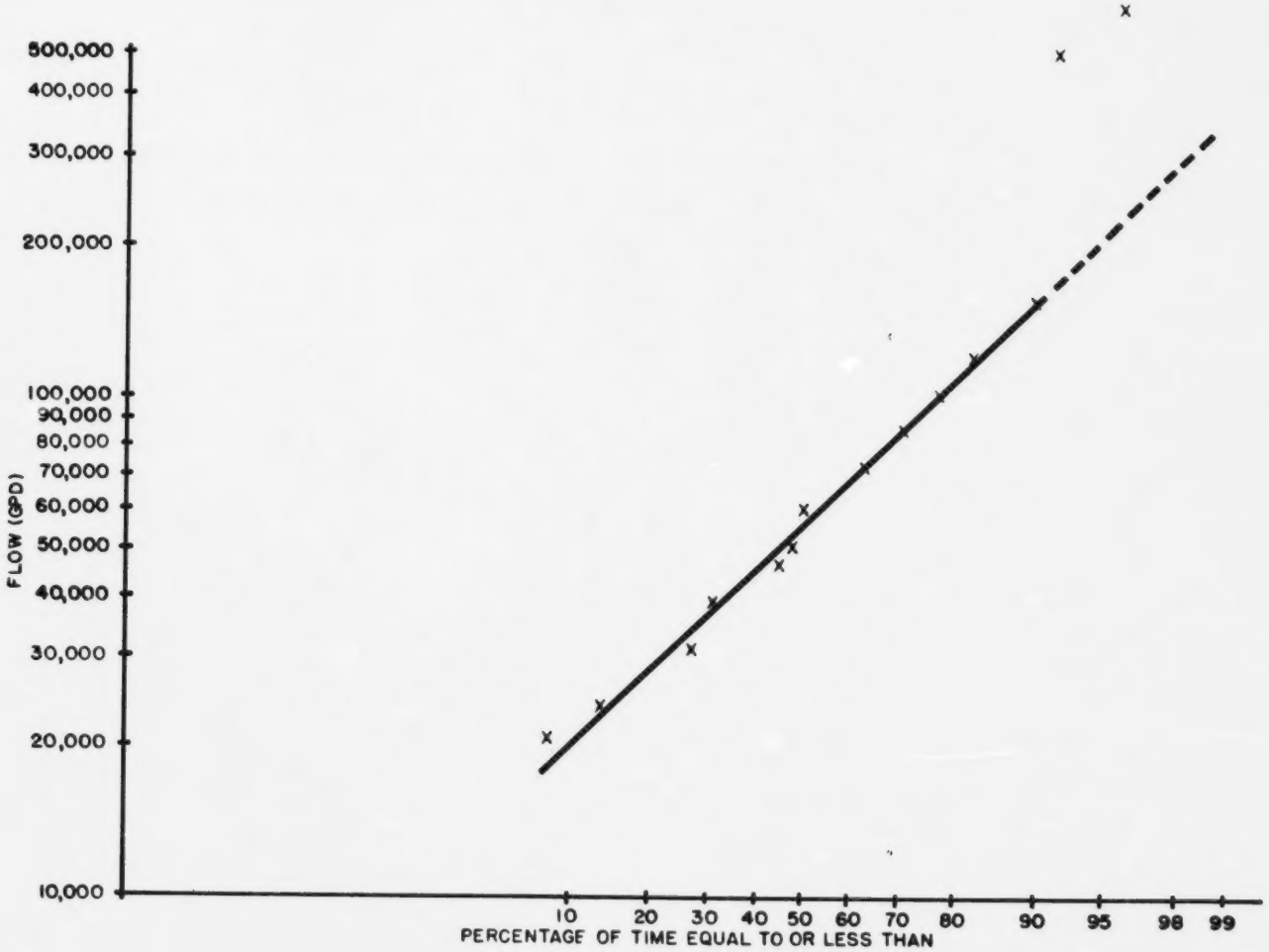


FIGURE 13. STATISTICAL VARIATION OF MINE DRAINAGE FLOW

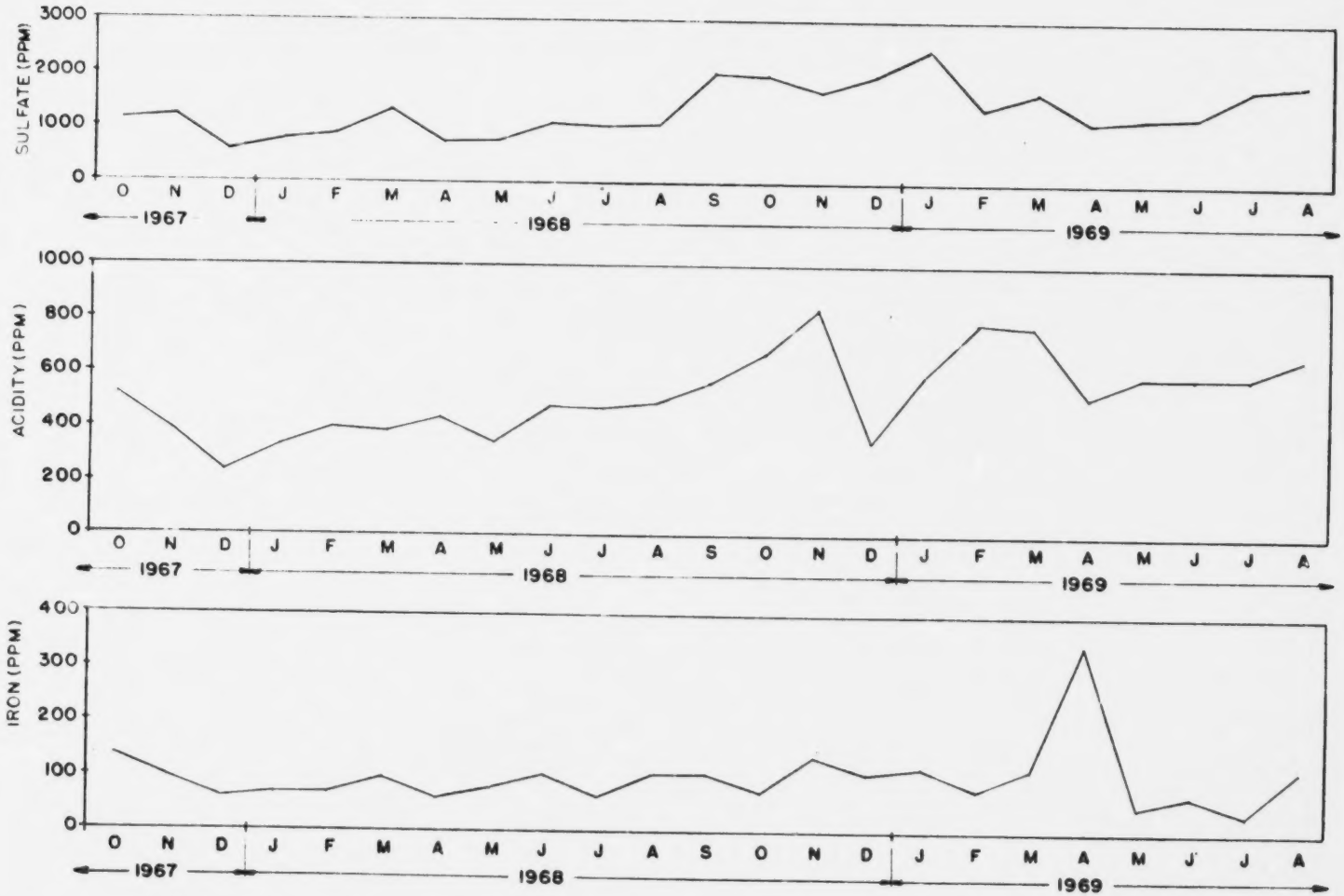


FIGURE 14. IRON, ACID & SULFATE CONCENTRATIONS IN MINE ACID FLOW

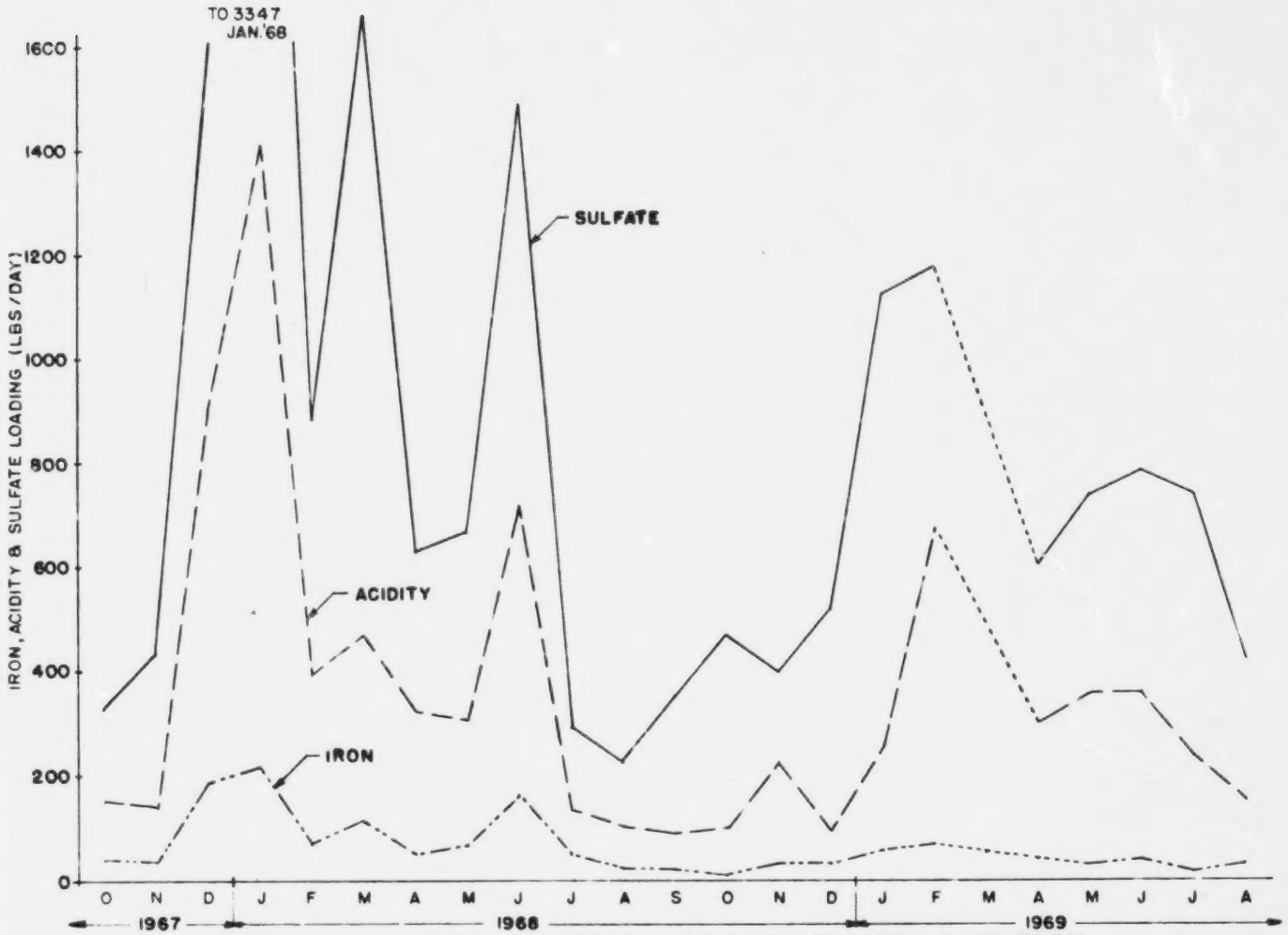


FIGURE 15. IRON, ACIDITY & SULFATE IN MINE ACID FLOW

TABLE I

PRECIPITATION IN VICINITY OF

KEYSTONE STATE PARK

(Average of Measurements at Blairsville, Vandergrift & Derry)

Inches of Precipitation

1967		1968		1969	
Jan.	1.28	Jan.	2.47	Jan.	2.70*
Feb.	2.82	Feb.	1.25	Feb.	1.03*
March	6.59	March	3.39	March	1.45*
April	4.55	April	2.05	April	4.54*
May	4.21	May	6.88	May	2.57*
June	1.69	June	1.61	June	3.64*
July	5.02	July	4.15	July	6.01
Aug.	3.88	Aug.	4.69	Aug.	2.16
Sept.	3.50	Sept.	2.80	Sept.	2.15
Oct.	3.02	Oct.	1.93	Oct.	2.81
Nov.	2.82	Nov.	3.85	Nov.	3.12
Dec.	2.46	Dec.	3.80	Dec.	4.93
ANNUAL	41.84		38.87		37.11

* No data from Derry. Donegal data used.

SECTION VI

GROUNDWATER MONITORING STATIONS

Location and Description of Monitor Wells

In order to provide the means of evaluating the impact of the sealing of the mine on groundwater in the area, a set of groundwater monitor wells were drilled in the locations shown on Figure 16.

Well A-2, located on top of the hill above the mine, was drilled to a depth of 200 feet, or to approximately 15 feet of the top of the mine, in order to evaluate the dewatering effects on the strata comprising the hill above the mine by the mined area. Two wells were originally proposed, one on each of the two rounded hilltops; however Well A-1 was later eliminated.

Wells B-1, B-2 and B-3 were drilled for the purpose of monitoring the groundwater in the immediate surrounding area in order to determine its response to the inundation of the mined area. Drilling depths were 230 feet, 225 feet and 200 feet respectively.

Wells C-1 and C-2 near to Keystone Lake and Creek, were drilled to 100 feet below their bottom elevations in order to give warning of possible deep flow lines and inputs of mine drainage polluted groundwater through the bottom of the lake or stream as a response to vertical pressure buildup as the mine fills. Depth of C-1 is 156 feet, and the depth of C-2, 110 feet.

All of the monitor wells are 6 inches diameter with 6-1/4" I.D. casing extending from 1 foot above grade to below bedrock. A screwed cap is provided on each well to prevent entry of foreign matter. Ten feet high markers, consisting of 6 inch diameter plates mounted on 1-1/2" diameter pipe, were erected at each monitor well to facilitate location and identification. A typical monitor well is shown on Figure 17.

Water was encountered during drilling of all the wells except well A-2 located on the crest of the hill. In general the wells at higher elevations such as B-1 and B-2 yielded small quantities of water. At wells C-1 and C-2 which are at a low elevation and lie close to the lake and stream, water was encountered at two separate elevations.

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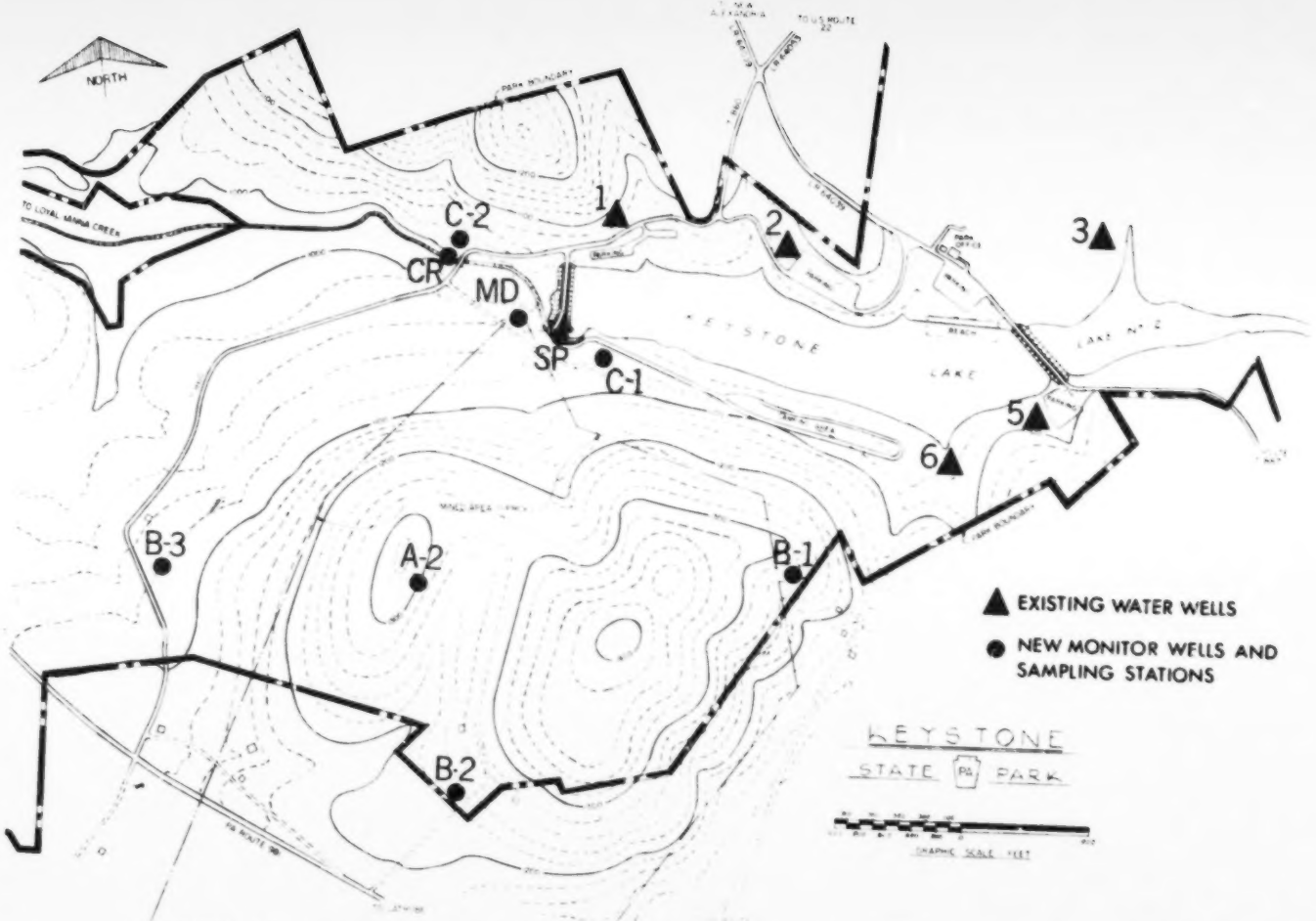

FIGURE 16. LOCATION OF WELLS AND SURFACE SAMPLING STATIONS

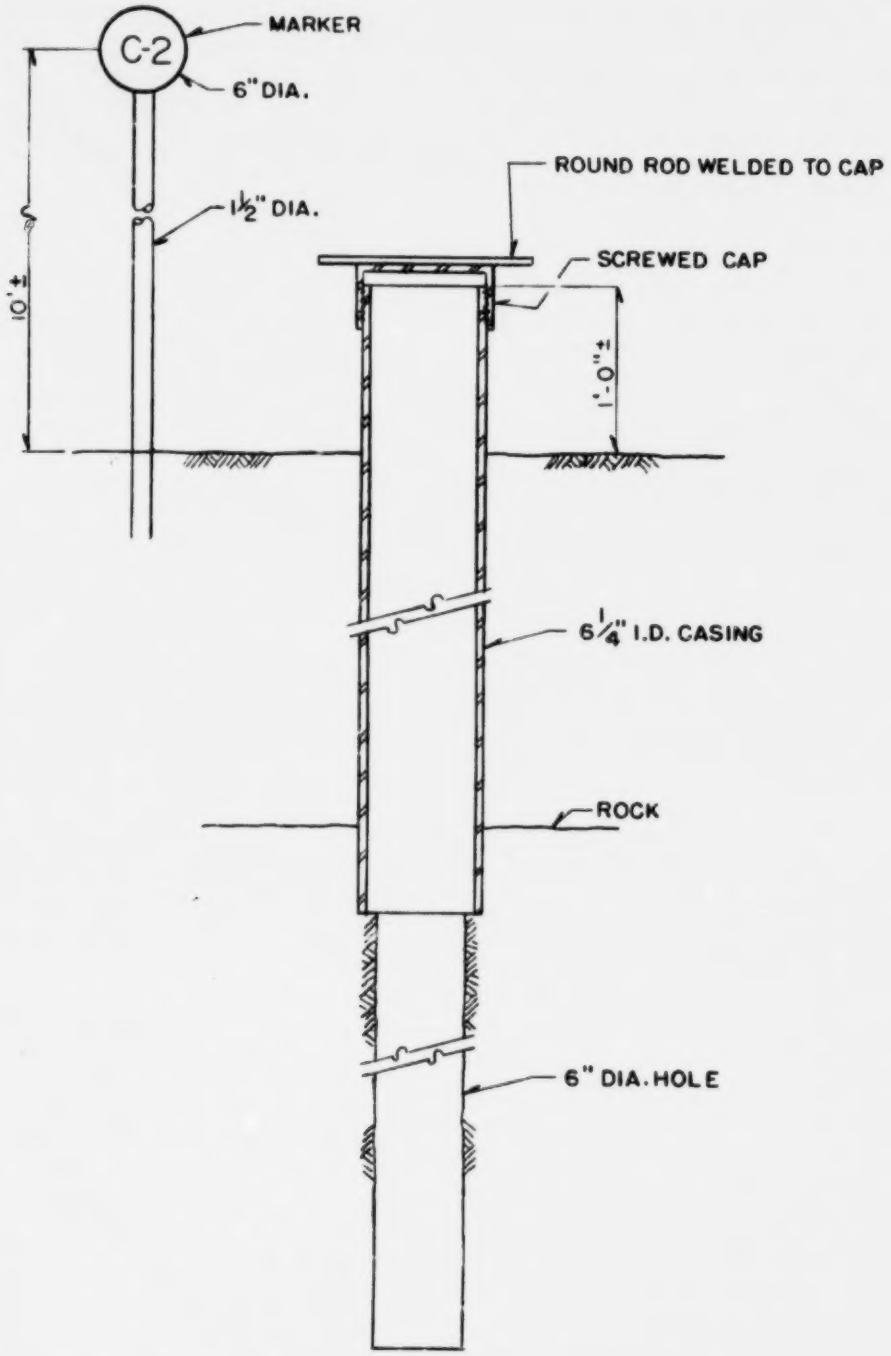

FIGURE 17. TYPICAL GROUNDWATER MONITOR WELL

The drilling logs of the monitor wells are tabulated on Table 2, and logs of water wells previously drilled in the park on Table 3, as an aid to defining the stratigraphy of the area for future interpretation of groundwater changes resulting from water buildup in the mine. The locations of the existing water wells are shown on Figure 16. Well No. 4 was not completed.

Sampling Program

In addition to the groundwater monitoring wells, surface sampling stations SP and CR were established upstream and downstream of the point where the mine drainage entered the creek and at the mine opening itself, designated station MD. Location of these sampling points are shown on Figure 16.

Since the surveillance program has been postponed, there is of course no data reflecting a change in the hydrogeological environment due to mine water impoundment. However, samples were taken from the monitor wells and surface sampling stations on a more-or-less weekly schedule over a two-month period prior to the scheduled sealing, in order to establish background data on water quality and level. These samples were analyzed for pH, total iron, sulfate, acidity and total solids. On each sampling tour the water level in the monitor well was measured.

The data from the "pre-sealing" sampling program is presented on Tables 4 through 11. At stations C-1 and C-2 samples were taken from two depths approximately coincident with the levels at which water was encountered during drilling. Monitor well A-2 was dry throughout the sampling period.

Some observations concerning the analytical data can be made. Iron concentrations were generally higher in the samples taken at the higher level in wells C-1 and C-2 indicating possible influence of mine drainage. Total solids concentrations in the samples taken January 20 at Sta. C-2 showed a sudden three-fold increase, but there was no corresponding increase in acidity, iron or sulfate concentration. On the contrary there was a reduction in acidity. It is believed that this sudden change in groundwater quality was due to contamination by a cement-flyash grout mixture that was pumped into the west entry the preceding week. This reinforces the evidence of contamination of well C-1 by water from the mined area.

TABLE 2

DRILLING LOGS OF MONITOR WELLS

Well A-2		Well B-1		Well B-2		Well B-3		Well C-1		Well C-2	
Strata Depth	Description	Strata Depth	Description	Strata Depth	Description	Strata Depth	Description	Strata Depth	Description	Strata Depth	Description
0-4	Clay	0-10	Sand	0-18	Clay	0-1	Topsoil	0-9	Topsoil & Clay	0-8	Topsoil & Clay
4-21	Sand Rock	10-14	Clay	18-61	Shale	1-16	Clay	9-45	Sand Rock	8-10	Shale
21-33	Shale	14-35	Shale	61-63	Coal	16-21	Shale	45-49	Coal	10-28	Solid Rock
33-49	Sand Rock	35-37	Sand Rock	63-66	Fire Clay	21-26	Solid Rock	49-55	Shale	28-30½	Coal
49-56	Shale	37-55	Shale	66-77	Sandy Shale	26-28	Shale	55-62	Sand Rock	30½-34	Shale
56-67	Sand Rock	55-81	Sand Rock	77-120	Sand Rock	28-39	Solid Rock	62-72	Shale	34-38	Sand Rock
67-83	Shale	81-124½	Shale	120-123	Coal	39-43	Coal	72-85	Sand Rock	38-40	Shale
83-92	Sand Rock	124½-125	Coal	123-126	Fire Clay	43-46	Fire Clay	85-90	Sandy Shale	40-45	Limestone
92-94	Shale	125-127	Fire Clay	126-146	Sand Rock	46-52	Solid Rock	90-91	Coal	45-70	Shale
94-94½	Coal	127-134	Shale	146-159	Shale	52-79	Shale	91-100	Shale	70-75	Sand Rock
94½-107	Fire Clay	134-141	Sand Rock	159-183	Sand Rock	79-98	Solid Rock	100-123	Sand Rock	75-84	Shale
107-123	Sandy Shale	141-156	Sandy Shale	183-186	Shale	98-102	Shale	123-134	Shale	84-93	Sand Rock
123-145	Sand Rock	156-168	Sand Rock	186-190	Coal	102-104	Coal	134-137	Sandy Shale	93-95	Shale
145-146	Shale	168-169½	Coal	190-192	Fire Clay	104-106	Clay	137-151	Shale	95-104	Sandy Shale
146-148	Coal	169½-206	Sand Rock	192-213	Sand Rock	106-110	Solid Rock	151-155	Coal	104-108	Sand Rock
148-151	Sandy Shale	206-215	Sandy Shale	213-218	Shale	110-111	Coal	155-156	Shale	108-110	Shale
151-200	Solid Rock	215-217	Sand Rock	218-224	Coal	111-126	Solid Rock				
		217-222	Sandy Shale	224-225	Fire Clay	126-135	Shale				
		222-230	Sand Rock			135-140	Coal				
						140-200	Shale				
	Water at 125'			Water at 176'			Water at 49'		Water at 49', 140'		Water at 28', 65'

TABLE 3

DRILLING LOGS OF EXISTING PARK WELLS

Well No. 1		Well No. 2		Well No. 3		Well No. 5		Well No. 6	
Strata Depth	Description	Strata Depth	Description	Strata Depth	Description	Strata Depth	Description	Strata Depth	Description
0-18	Clay	0-9	Clay	0-10	Clay	0-20	Clay	0-15	Clay
18-30	Gray Shale	9-11	Dark Shale	10-50	Gray Shale	20-65	Gray Shale	15-40	Gray Shale
30-32	Coal	11-25	Gray Shale	50-60	Gray Sand	65-80	Gray Sand	40-47	Gray Sand
32-70	Gray Shale	25-37	Dark Shale	60-65	Coal	80-85	Gray Shale	47-48	Coal
70-75	Gray Sand	37-50	Gr. Sand Rock	65-115	Gray Sand	85-87	Gray Sand	48-50	Gray Shale
75-80	Coal	50-52	Coal	115-120	Gray Shale	87-90	Coal	50-70	Gray Sand
80-85	Gray Shale	52-55	Gray Shale	120-125	Gray Sand	90-100	Gray Shale	70-90	Gray Shale
85-110	Gray Sand	55-60	Sand Rock	125-130	Coal	100-110	Gray Sand	90-100	Gray Sand
110-165	Gray Shale	60-70	Gray Shale	130-150	Gray Shale	110-140	Gray Shale	100-105	Brown Shale
165-170	Coal	70-75	Sand Rock	150-155	Coal	140-150	Gray Sand	105-110	Coal
170-210	Gray Sand	75-80	Gray Shale	155-175	Gray Shale	150-160	Coal	110-135	Gray Shale
210-245	Gray Shale	80-82	Black Shale	175-205	Gray Sand	160-185	Gray Shale	135-140	Coal
245-270	Gray Sand	82-130	Gray Shale	205-210	Gray Shale	185-190	Coal	140-150	Gray Shale
270-300	Gray Shale and Sand	130-135	Sand Rock			190-200	Gray Shale	150-175	Gray Sand
		135-145	Sandstone			200-220	Gray Sand	175-190	Gray Shale
		145-170	Gray Shale			220-295	Gray Shale		
						295-300	Gray Sand		
Water at 50', 110', 245'		Water at 37', 40', 55', 105', 135', 160'		Water at 25', 150', 175'		Water at 35', 80', 200'		Water at 30', 45', 65', 100', 115'	

TABLE 4
RESULTS OF ANALYSES
SAMPLING STATION MD

	11-19-71	11-30-71	12-8-71	12-13-71	12-21-71	1-6-72	1-13-72	1-20-72	1-28-72
pH	2.84	2.62	2.73	2.72	2.71	2.82	2.86	2.88	2.91
Iron	105	348	67.0	75	57.2	62.4	56	56.5	46.2
Sulfate	1930	1000	650	650	666	544	532	600	620
Acidity ("hot")	535	603	407	425	424	369	460	458	485
T. Solids	8172	2811	1281	1561	1371	2025	1179	1360	8694

All concentrations in parts per million

TABLE 5
RESULTS OF ANALYSES
SAMPLING STATION CR

	11-19-71	11-30-71	12-8-71	12-13-71	12-21-71	1-6-72	1-13-72	1-20-72	1-28-72
pH	6.27	7.62	7.20	7.47	7.56	5.85	5.73	7.26	6.83
Iron	5.29	8.3	5.08	6.6	3.8	2.2	2	3.5	2.6
Sulfate	23.5	16	34.0	51	45	26	34	42	33
Acidity	7.38	1.6	3.1	1.6	1.4	11.7	6.1	3.6	6.3
T. Solids	239	279	116	189	104	156	158	206	141

All concentrations in parts per million

TABLE 6
RESULTS OF ANALYSES
SAMPLING STATION SP

	11-19-71	11-30-71	12-8-71	12-13-71	12-21-71	1-6-72	1-13-72	1-20-72	1-28-72
pH	7.50	7.24	7.29	7.96	7.93	7.85	7.26	7.94	6.80
Iron	0.41	0.8	2.46	4.3	1.4	ND	1	ND	1.0
Sulfate	26.5	26	26.5	16	15	16	17	16	15
Acidity	2.0	3.3	3.1	1.1	1.2	1.3	3.2	1.3	10.9
T. Solids	98	109	101	86	78	96	141	99	179

All concentrations in parts per million

TABLE 7
RESULTS OF ANALYSES
SAMPLING STATION C-1

		11-19-71	11-30-71	12-8-71	12-13-71	12-21-71	1-6-72	1-13-72	1-20-72	1-28-72
Water Level (ft)		1044	1043	1046	1047	1044	1043	1043	1044	1044
pH	(U)	7.68	8.11	8.01	8.51	8.49	7.67	7.76	8.54	7.87
	(L)	7.63	-	7.87	8.53	8.42	7.95	7.57	8.35	8.31
Iron	(U)	0.93	1.8	12.4	10.7	12.5	9.0	12	9.1	8.0
	(L)	1.58	-	12.4	8.6	8.1	5.4	8	6.9	5.8
Sulfate	(U)	12.0	15	15.7	ND	2	2	5	2	4
	(L)	10.5	-	12.8	5	4	2	4	2	4
Acidity	(U)	7.0	0.6	1.2	4.2	2.6	7.9	7.4	5.0	4.6
	(L)	5.75	-	4.2	3.8	2.4	3.8	11.5	ND	5.5
T. Solids	(U)	294	283	385	556	525	357	381	356	313
	(L)	387	-	407	358	373	346	435	328	312

All concentrations in parts per million

(U) Sample taken at upper elevation, approximately 1030'
(L) Sample taken at lower elevation, approximately 940'
ND None Detected

TABLE 8
RESULTS OF ANALYSES
SAMPLING STATION C-2

		11-19-71	11-30-71	12-8-71	12-13-71	12-21-71	1-6-72	1-13-72	1-20-72	1-28-72
Water Level (ft)		1011	1011	1010	1012	1010	1012	1012	1013	1013
pH	(U)	7.24	7.02	6.76	8.50	8.44	7.09	6.93	8.60	8.55
	(L)	7.69	8.26	7.57	8.89	8.80	7.55	7.47	8.73	8.83
Iron	(U)	3.59	10.4	10.3	12.7	10.8	14.0	15	15.8	10.8
	(L)	3.49	6.7	7.77	8.8	7.0	8.6	9	12.5	8.5
Sulfate	(U)	29.7	33	31.0	16	16	16	14	5	3
	(L)	18.5	11	19.2	5	5	6	8	5	4
Acidity	(U)	9.25	10.8	4.0	1.2	0.9	11.2	22.8	6.2	3.5
	(L)	3.75	0.4	7.3	8.0	7.1	10.8	11.0	6.0	3.8
T. Solids	(U)	251	209	183	238	173	308	320	983	783
	(L)	458	193	302	464	269	369	352	911	656

All concentrations in parts per million

(U) Sample taken at upper elevation, approximately 990'
(L) Sample taken at lower elevation, approximately 955'
ND None Detected

TABLE 9
RESULTS OF ANALYSES
SAMPLING STATION B-1

	12-13-71	12-21-71	1-6-72	1-13-72	1-20-72
Water Level (ft)	1219	1217	1218	1219	1218
pH	8.64	8.54	7.78	7.53	8.55
Iron	9.9	8.7	3.3	8	5.8
Sulfate	13	16	15	13	11
Acidity	2.8	2.4	2.9	4.3	2.1
T. Solids	651	649	439	652	443

All concentrations in parts per million

TABLE 10
RESULTS OF ANALYSES
SAMPLING STATION B-2

	11-30-71	12-8-71	12-13-71	12-21-71	1-6-72	1-13-72	1-20-72
Water Level (ft)	1177	1177	1174	1179	1183	1188	1189
pH	7.19	7.15	8.08	8.05	7.50	7.21	8.10
Iron	4.2	6.60	7.3	7.8	6.1	5	7.8
Sulfate	24	24.2	7	7	7	8	7
Acidity	5.1	17.6	1.0	1.1	16.0	28.9	1.3
T. Solids	533	422	449	417	555	393	404

All concentrations in parts per million

TABLE 11
RESULTS OF ANALYSES
SAMPLING STATION B-3

	11-19-71	11-30-71	12-8-71	12-13-71	12-21-71	1-6-72	1-13-72	1-20-72	1-28-72
Water Level (ft)	1049	1055	1056	1055	1057	1059	1060	1060	1060
pH	6.74	7.93	6.33	8.27	8.10	6.50	6.64	8.24	7.67
Iron	2.79	ND	6.49	11.3	12.5	4.9	26	16.9	13.4
Sulfate	11.0	15	24.7	6	5	13	9	4	7
Acidity	10.75	0.8	14.9	0.6	1.6	18.1	16.8	0.6	2.3
T. Solids	260	350	519	503	499	325	501	441	234

All concentrations in parts per million

There was a noticeable decrease in iron, sulfate, acidity and total solids concentrations in the mine drainage after the first two sampling tours. This may have been due to dilution from increased runoff resulting from frequent rains during this period, or to changes in the mine environment brought about by the construction activity, or both. Excavation of the fanway released impounded acid water and permitted this corridor to drain freely.

SECTION VII

MINE SEALING OPERATIONS

The decision to place two double-bulkhead concrete seals and only one experimental chemical grout seal was prompted by the higher-than-expected cost of the grouting materials which were determined by laboratory testing to be suitable for the proposed mine sealing method. However, there were other areas in which it was felt benefits could be derived by substitution of the concrete seals at this site.

1. The potential hydraulic head that could develop on the seals if the mine filled to its highest level was 84 feet. The maximum head on any existing seal of this type was about 35 feet. Therefore, it was possible that the opportunity would be afforded to evaluate the double bulkhead concrete seals under a higher pressure than that to which they had previously been exposed.

2. Installation of previous double bulkhead seals included grout stabilization of the retaining stone bulkheads prior to placement of the concrete seals. It was believed that this step could be eliminated. Installation of double bulkhead concrete seals at the Keystone State Park test site permitted testing this modification of the construction procedure.

Double Bulkhead Seals

The double bulkhead concrete seals were installed in the east and west mine entries. The bulkheads are normally constructed by injecting coarse aggregate through vertical drill holes across the mine corridor and vibrating the material so that an alignment of intersecting truncated cones are formed with a minimum of four feet diameter contact zone at the mine roof. Grout is injected into the bulkheads and then a concrete plug is injected into the space between the bulkheads.

Six-inch diameter injection holes were drilled across the east and west entries for placement of the bulkheads and concrete seal. The alignment of the holes was not exactly perpendicular to the bearing of the entries because they were drilled before the middle entry was opened to permit a survey. This however would be the rule rather than the exception since accurate mine maps are seldom available and openings often have to be established by exploratory drilling. From the drilling logs the east and west entries were estimated to be 12 to 14 feet wide and from 4 to 8 feet high depending on exact location.

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One hundred tons of aggregate, Pennsylvania Department of Highway 2-B size and grading (1/2"+), were placed and vibrated in the west entry through the applicable drill-holes, sixty tons for the forward bulkhead and forty tons for the rear bulkhead. In the east entry the forward bulkhead consisted of seventy-seven tons and the rear bulkhead sixty-eight tons of aggregate.

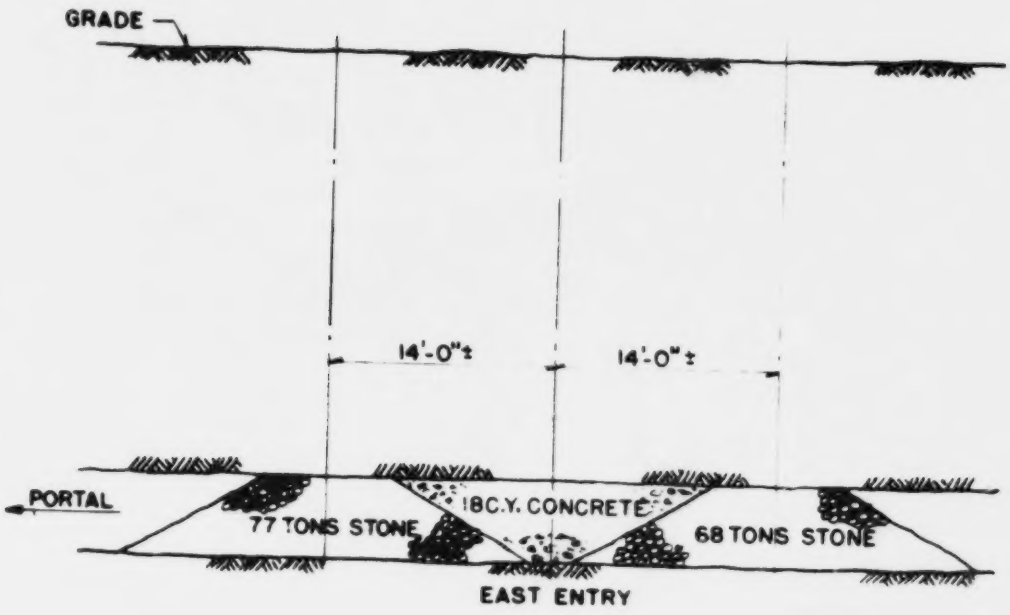
Attempts at taking pictures in the mine through boreholes to examine the bulkhead location and assess the integrity of the stone bulkheads were unsuccessful due to water and high humidity which resulted in condensation on lens surfaces. A considerable amount of water was backed up in the west entry, and attempts to dewater the area by excavation in front of the entry, and by pumping were not completely successful.

It was decided to inject the concrete seals without dewatering. A laboratory test showed that the concrete would set satisfactorily when poured into an acid solution simulating the mine acid, and based on the dimensions of the mine cavity and the quantities of stone placed it was concluded that in all probability the bulkheads were satisfactory. Eighteen cubic yards of concrete were poured in the east entry and thirty-five cubic yards in the west entry. The completed seals are illustrated in Figure 18.

The center plug areas of the seals were pressure grouted through drill holes extending entirely through the concrete plug to below the mine floor. A total of 1472 cubic feet of flyash-cement grout were injected in the east entry seal. For grouting of the west seal calcium chloride was added as an accelerator because some seepage was noted below this entry indicating possible water movement through the seal area. A total of 3584 cubic feet of grout were injected at this location.

The total cost for both double bulkhead seals in place is estimated at $30,000. This includes the grouting of the center plugs, but no curtain grouting.

Test holes were drilled in the center plug areas of the double bulkhead seals downstream of the injection holes five months after the seals were placed. These holes were cored all the way through the seals to the mine floor, and revealed no discontinuity of material in either of the two concrete seals, therefore it is apparent that the mine entries are completely filled in the area of the seals. Core recovery, from the mine roof to the mine floor, was



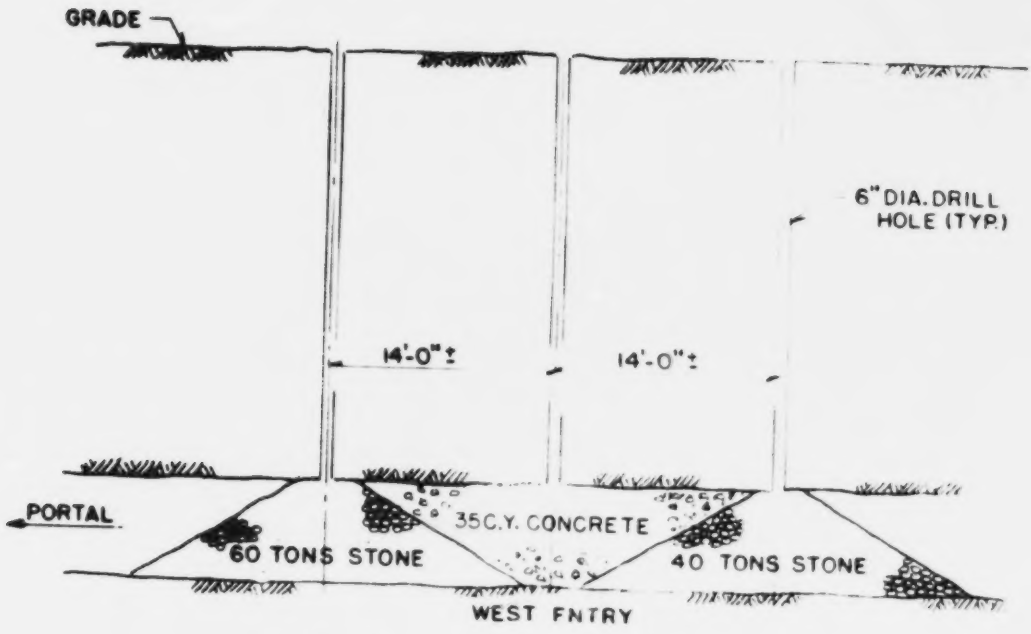


FIGURE 18. DOUBLE BULKHEAD SEALS

51% for the east seal and 40% for the west seal. This represents a relatively high loss but is not unusual for this type of application and may indicate only that portions of the cement matrix are weak enough to be shattered by the core drilling. The effectiveness of the total mass as a seal would not necessarily be impaired. Pressure testing would be required in order to assess the effectiveness of the material within the seal area as a hydraulic seal.

The boring logs showed that settling of the concrete took place after the seals were poured. This could have been due in part to displacement of gob and migration of material into or through the stone bulkheads as well as movement of the bulkheads themselves. In the east seal nine inches of flyash-cement grout were found above the concrete, and in the west seal twenty-two inches of grout were recovered from between the mine roof and the concrete seal. This grout usage offset any saving that was realized by elimination of the grouting of the bulkheads, therefore there appears to be no advantage to elimination of this step in the construction procedure.

Sealing of Air Vent

The existing 12" diameter vent pipe, located on the first cross connection between the main entry and the fanway as shown on Figure 3, was removed and replaced with a 4-inch stainless steel pipe which was concreted in place. This pipe was fitted with a pressure gauge for possible use in monitoring the progress of water buildup in the mine after it is sealed. The gauge is mounted on a flange which may be removed entirely for sampling or measuring water level when this is below the gauge elevation. A 4" valve is also provided to serve as a possible relief device should it become necessary to lower the water level in the mine after it has exceeded the elevation of the valve. A sketch of the gauge-relief pipe is shown on Figure 19.

Construction of Safety Bulkhead

Because of the experimental nature of the proposed chemical grout-flyash seal, a reinforced concrete safety bulkhead was constructed in the middle entry which was selected for the test of the material. The entry, which served as the fanway when the mine was worked, was reestablished by excavation, and a diversion channel was cut to divert the drainage directly to the creek. For protection and security of the opening, a wooden entry way was built twelve feet out from the face of the mine, with cyclone fence double gate at the end. The entrance is shown on Figure 20.

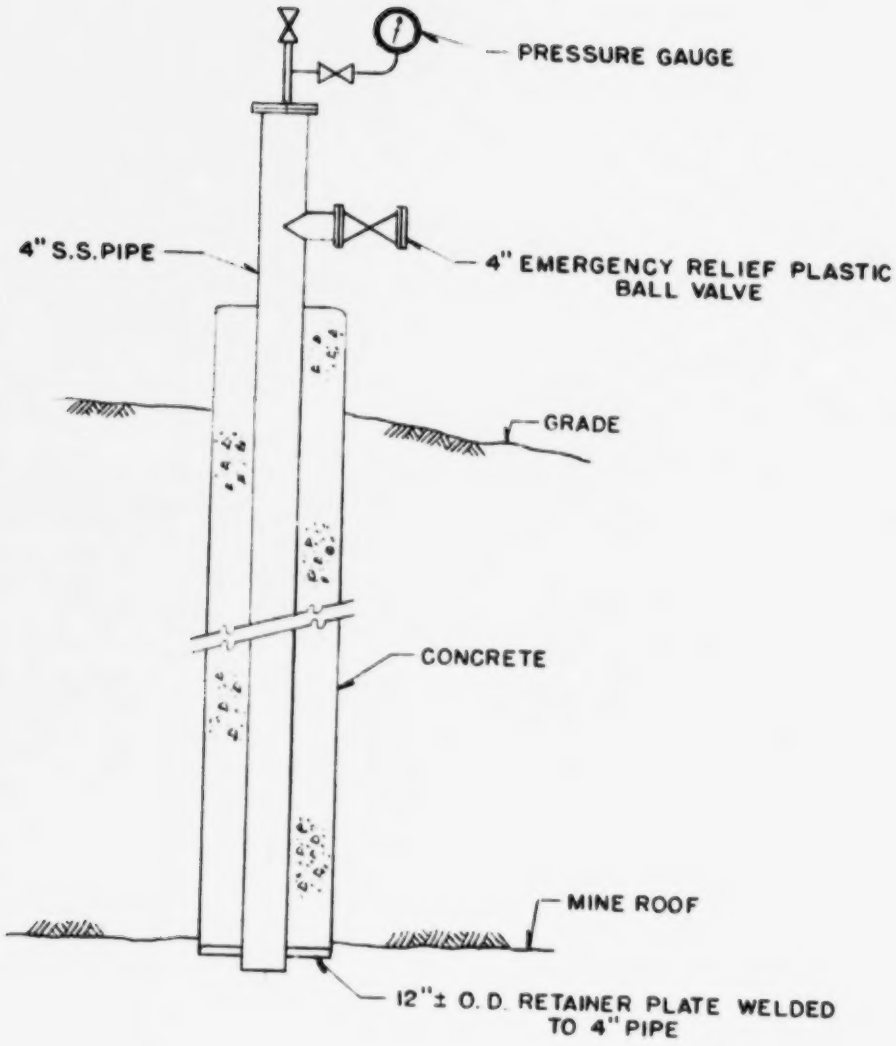


FIGURE 19. PRESSURE GAUGE-RELIEF PIPE INSTALLED IN PLACE OF OLD AIR VENT

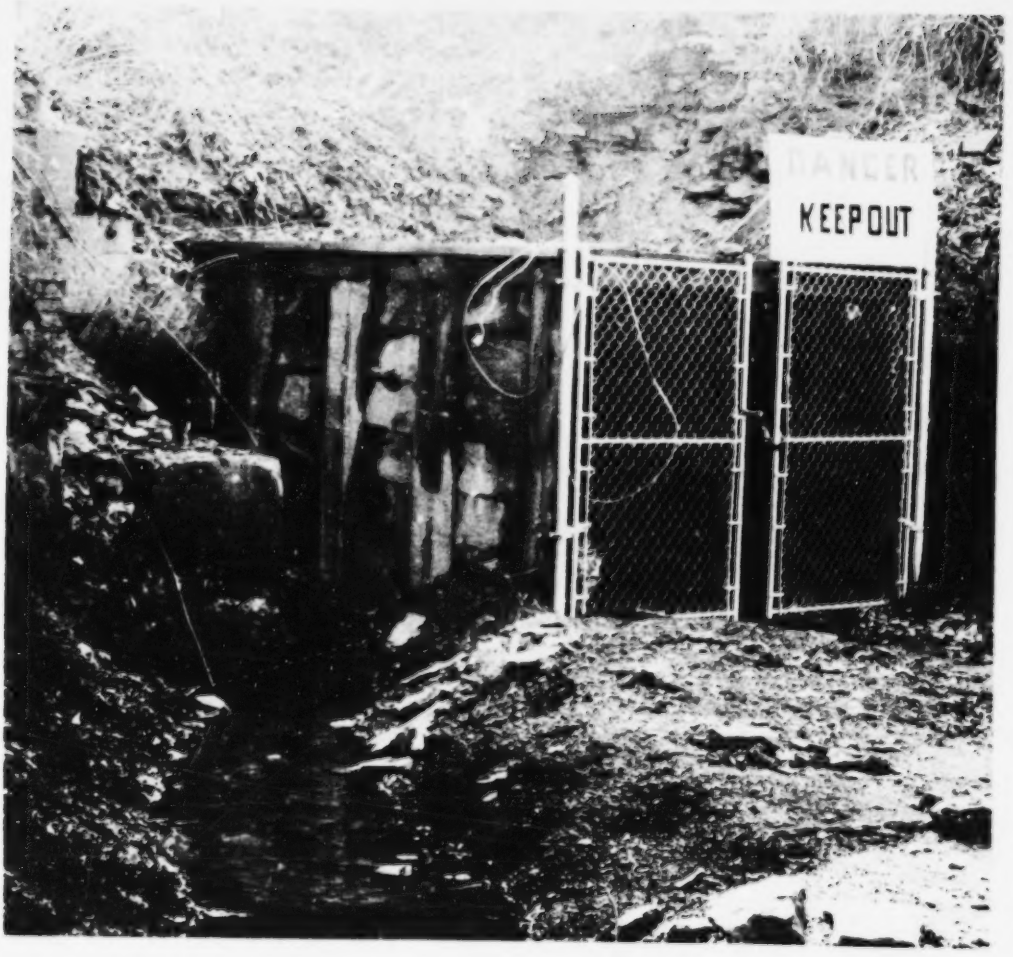


FIGURE 20. PROTECTION OF EXCAVATED MINE ENTRY

The reinforced concrete bulkhead was located approximately 18 feet in from the face of the mine. A drainage channel and 6" drain pipe was installed in the mine floor to permit free drainage of the mine while the bulkhead was being built. A 4-inch diameter stainless steel pipe with plastic ball valve was located approximately two feet up from the mine floor to permit sampling, and to aid in the sealing operation special plexiglass windows were included for observation and light insertion. Bulkhead details are shown on Figure 21. A photograph of the completed installation is shown on Figure 22.

Injection Nozzle Tests

Preliminary tests in the laboratory, Figures 23 and 24, showed that an AM9-flyash slurry consisting of 15 pounds of flyash per gallon of 15% grout solution could easily form a self-supporting mass with 20 to 25 degrees angle of repose, but that proper distribution of the slurry was essential to establishment of complete closure at the mine roof. It was felt that this distribution could be accomplished through a single injection hole by use of a nozzle that would direct the slurry outward and slightly upward so that the seal is built up from the outer extremities as previously illustrated in Figure 2.

Tests were conducted with an injection nozzle consisting of two 3/8" nozzles at 180 degrees, inclined upward at 30 degrees from the horizontal. To avoid plugging of the injection piping when using short gel times the initiator was added just ahead of the nozzle. As a result of the tests it was concluded that a satisfactory distribution could be achieved with the nozzle, and that mixing of the ammonium persulfate solution with the grout slurry just ahead of the nozzle was adequate to produce a controllable gel. The nozzle tests are illustrated on Figure 25. Pumping of the grout slurry was not continued to build up a plug in the test area in view of the high cost of the grout materials. It was hoped that with the viewing ports built into the reinforced concrete safety bulkhead the progress of the actual seal placement could be monitored closely enough so that precise step by step procedures would not have to be previously determined by large scale testing.

Injection of Gel Material

Due to cold weather injection of the AM9-flyash grout was delayed several weeks. It was decided to wait until at least two days of above freezing temperatures were reasonable assured before attempting to place the seal.

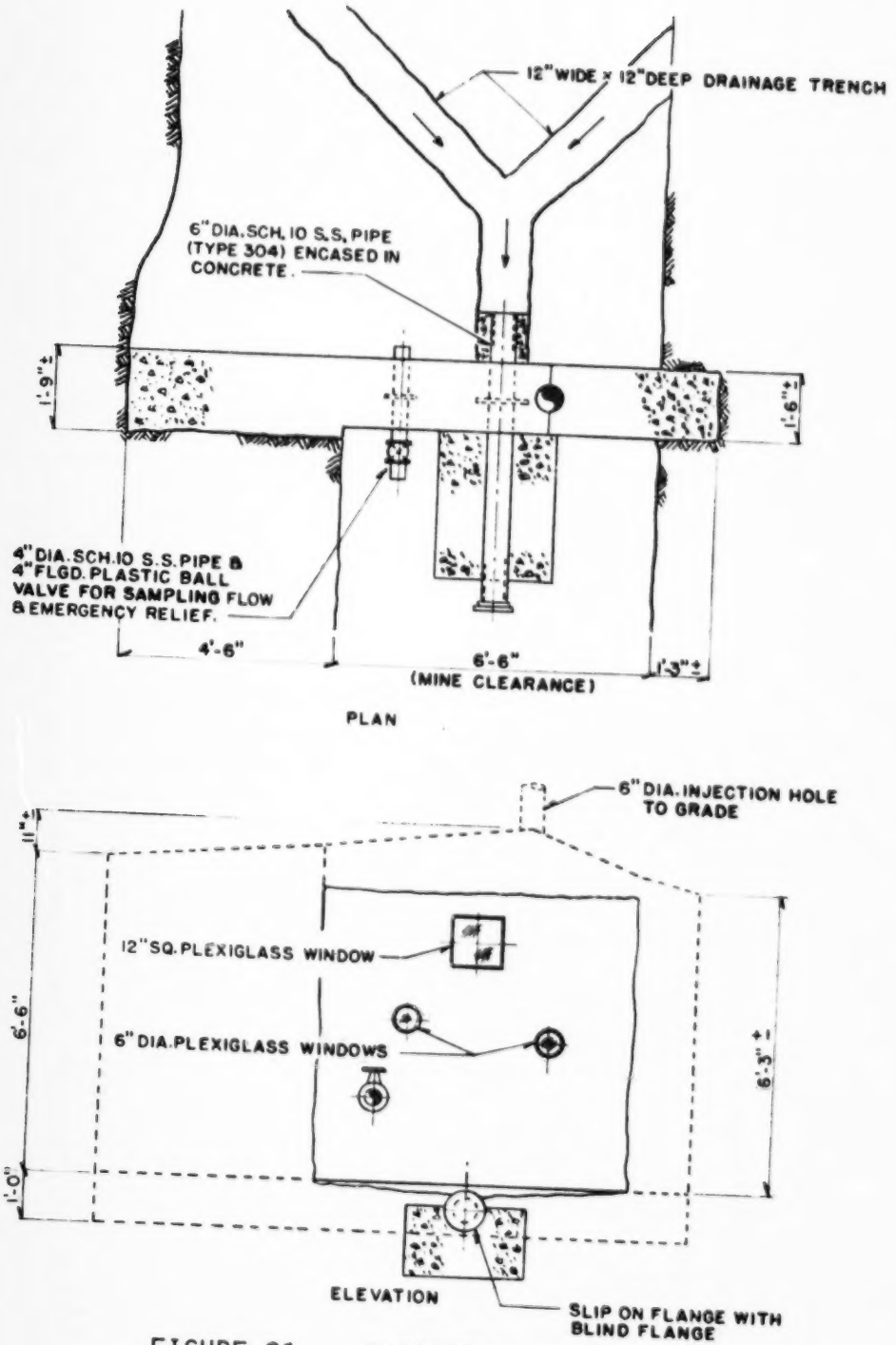


FIGURE 21. CONCRETE BULKHEAD

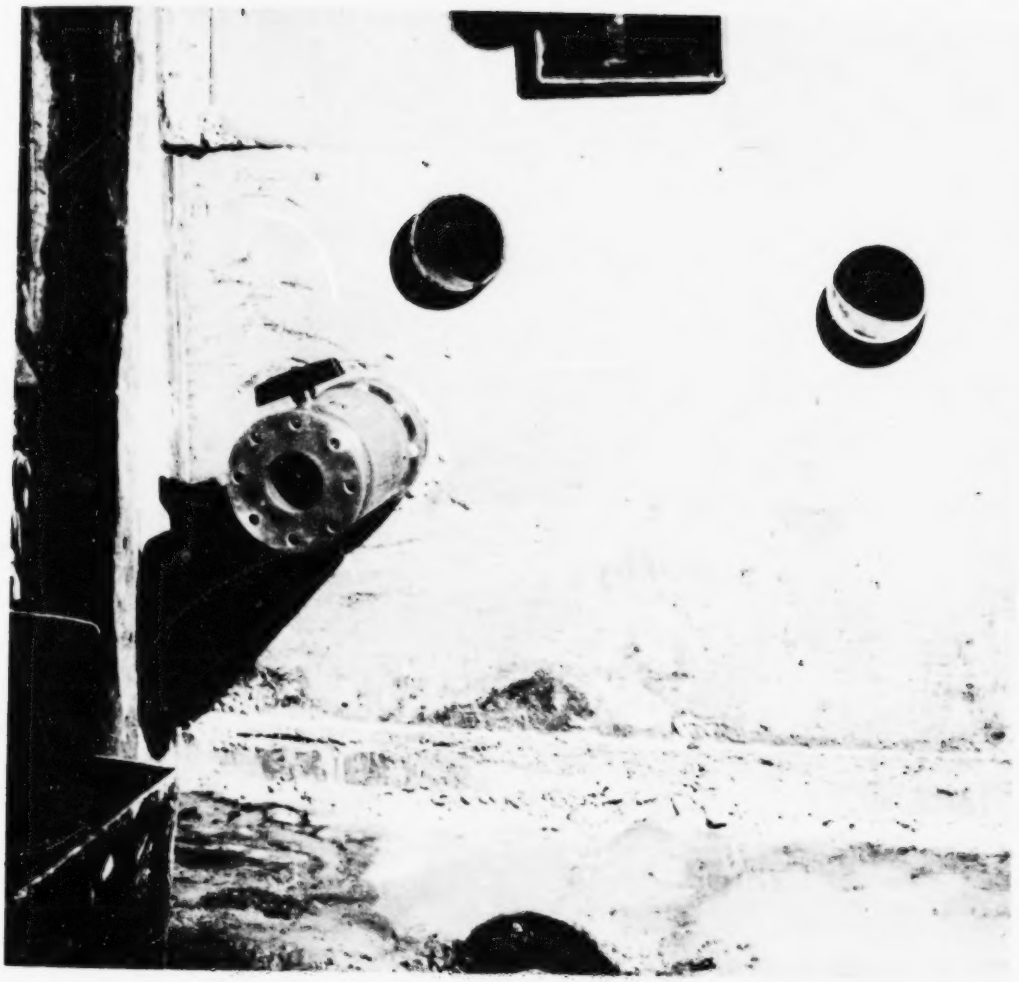


FIGURE 22. VIEW OF CONCRETE SAFETY BULKHEAD

FIGURE 23. BENCH SCALE TEST OF GEL MATERIAL

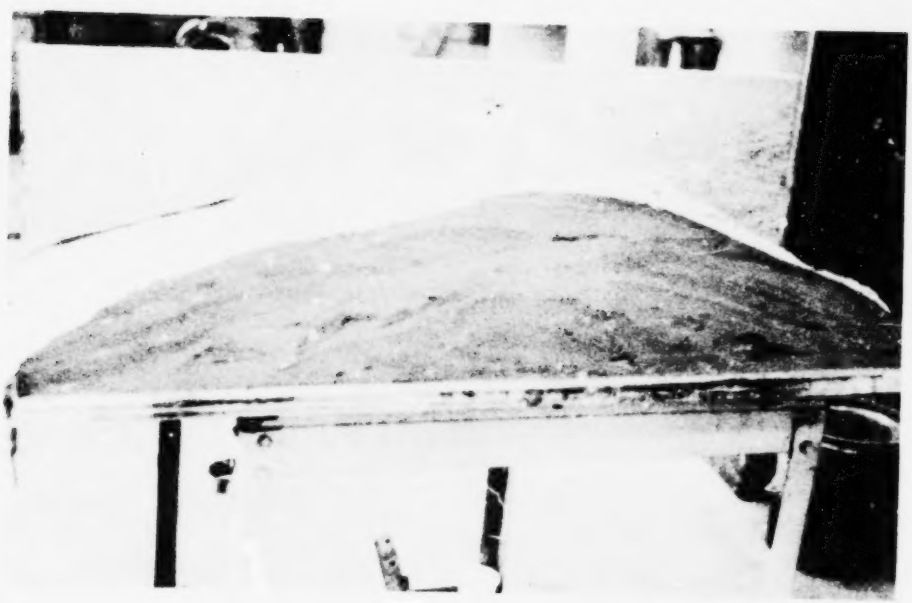


FIGURE 24. ANGLE OF REPOSE ACHIEVED IN LAB TEST

FIGURE 25. YARD TESTS OF INJECTION NOZZLE

On February 28, 1972, with a warm trend predicted, preparations were made for the grouting operation. The next day, final tests were run to check out equipment and determine approximate proportions and gel times, using water from the site at prevailing temperature and flyash from the batch to be used in the actual grout mix, and on March 1 injection of the grout into the mine began. Flyash, AM-9 and catalyst DMAPN were batch mixed in a 2500 gallon, two-compartment slurry batcher, shown on Figure 26 with a material weigh bin above it. From the batcher the slurry was pumped to a small hopper feeding progressive cavity type injection pump of 30 gpm capacity. Ammonium persulfate, the reaction initiator, was fed by a smaller pump into the injection pipe just ahead of the nozzle. The injection pipe and pumps are shown on Figure 27.

Lights were inserted in the 6" diameter ports in the safety bulkhead for illumination of the mine cavity, but visibility was poor due to condensation and obstructions which blocked view of the injection point. Figure 28 shows the view through the bulkhead.

The injection nozzle was oriented to direct the slurry stream toward the walls and the grout pumped at a rate of 30 gallons per minute with a gel time of approximately 15 seconds. The anticipated result of this procedure was that a wedge shaped mass would be built up on each side of the mine corridor, starting at the walls and sloping downward toward the middle where the mine drainage was observed to be flowing. With proper control of the gel time it was hoped that the two wedge shaped formations could be gradually extended into the drainage channel eventually damming the flow and causing it to spread out behind the grout dam. However, this was not successful. Observation of the drainage from the mine indicated that much of the grout material was being lost. The gel time was decreased from fifteen seconds to as low as five seconds with no success in stopping grout loss. A satisfactory gel was apparently achieved on both sides of the entry, as evidenced by inability to remove the catalyst injection hose when the operation was terminated, but the flow in the middle of the mine floor was too high to permit a gel to form.

The flow from the mine measured by a v-notch weir was found to be approximately 150 gallons per minute. This was considerably higher than the 40 to 50 gallons per minute measured a week earlier and was due to runoff brought about by the sudden onset of very warm weather. The air temperature rose to above 70°F during this period.

FIGURE 26. SLURRY BATCHER AND WEIGH BIN

FIGURE 27. SLURRY INJECTION PIPE AND PUMPING EQUIPMENT

FIGURE 28. VIEW OF MINE ENTRY THROUGH OBSERVATION WINDOW IN BULKHEAD

Due to the high flow much of the grout was diluted to the point where it failed to gel, and the material that did gel at the edge of the flowing water was washed away. Some gelled material was collected outside the mine entrance indicating that some of the grout had indeed formed weak gels which were transported away by the flowing water.

In view of the previously established high cost of grout materials and the difficulties experienced in applying the injection technique with the high mine flow, the decision was made after consultation with State and Federal project sponsors, to terminate the test. It was felt that the method may be successful in low flow situations, and with higher injection rate to minimize dilution and erosion of the grout, but the cost remained prohibitive.

Acid drainage abatement activities and sampling at the mine site have been interrupted to permit compilation and review of all information relative to the project prior to completion of the work. In order to retain the possibility of using the mine entry for further experimental work, the reinforced concrete safety bulkhead was left free-draining to minimize accumulation of gob which may block off the view ports.

Work remaining to complete normal abatement procedures at the Salem No. 2 mine, if no further experimental work is planned, consist of injection of a grout curtain in the strata adjacent to the mine entries.

SECTION VIII

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This report was prepared by Neville K. Chung, Dravo Corporation, Pittsburgh, Pennsylvania 15222.

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Chemical grout

27 Abstract

Laboratory testing of commercially available chemical grouts was conducted to evaluate their potential use, in conjunction with a cheap filler, for remote sealing of mine voids. By close control of the setting time and proper distribution of the grout slurry it was believed that a mine seal could be placed through a borehole from the surface without the benefit of retaining bulkheads.

A slurry mix consisting of an acrylamide grout with flyash or mine refuse as a filler was found to produce a strong controllable gel which resisted chemical attack in the laboratory over an eleven week exposure period.

An attempt to demonstrate a novel technique for application of the selected grout slurry in a mine entry with high flow was not successful. The results suggest that the technique may be applicable in dry or low flow situations. However, the estimated cost of a mine seal using the gel material is presently not competitive with existing methods.

Groundwater monitor wells were drilled for the purpose of determining the effect of mine sealing on groundwater conditions. Data reflecting pre-seal conditions was compiled, but because the sealing of the mine was not completed the monitoring program has been postponed.

Abstractor: Neville K. Chung

Institution: Dravo Corporation

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